PLANNING OF FEEDER BUS NETWORK FOR MRTS THROUGH INTERACTIVE GRAPHICS

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by

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CERTIFICATE

It is certified that the work contained in the thesis entitled "PLANNING OF FEEDER BUS NETWORK FOR MRTS THROUGH INTERACTIVE GRAPHICS", by Dipak Ghosh has been carried out under my supervision and that this work has not been submitted elsewhere for a degree.

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Dipak Ghosh.

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Abstract

This study is an effort to develop an interactive package for *planning and design of feeder network* for **Mass Rapid Transit System (MRTS)**. The interactive graphic system is an on line computer system so that the planner who defines the network can test the number of alternatives and select the optimal one. The program calculates the different parameters but the final selection lies on the user. If any routes are wrongly selected, the option is given to user to discard again. At the end it will display the final feeder bus route network.

The input required is the nodal and link details, O-D matrix, connectivity, spatial distribution of nodes in the zones. The influence area for each MRTS is being determined. The demand from each node to MRTS station is estimated. First, the network is displayed on the screen. For each MRTS station, the number of feasible routes are generated between the road terminal, selected by the user or by the program, and the MRTS station and evaluated by the parameter, called demand satisfied per kilometer. The routes with higher demand satisfaction is being selected. After the selection of optimal routes, the program schedules the buses in different routes. It determines the different parameters for each route such as maximum link flow, average link flow, total waiting time for the passengers, no of trips operated, no of buses to be operated, no of parking lots at the two terminals, total km operated, km operated per bus. The design of scheduling plan is done for four level of service and two period of operation. It also calculates the different system parameters such as fleet size, system waiting time, average waiting time, average load factor, km operated per bus etc.

The program is written in C language and uses X-Window graphics library for display. Delhi metropolitan area has been considered for the study purpose. The data is taken from existing studies. Designing of routes and scheduling plan of buses are carried out for the study area.

Chapter 1

Introduction

1.1 Prelude

Rapid urbanization is a worldwide phenomenon which posses critical problems especially for developing countries. The recent population growth trends indicate that most of the larger cities especially the metropolitan cities will double by the turn of the century. In this perspective the urban transport plays the necessary role in absorbing a large part of the overall increase in population.A faster rate of growth is to be expected in urban transport requirement to meet the growing demand.The resources available are scarce. So there is a need to plan and operate the urban transportation systems in more effective way.

Mass transportation is a means of improving the quality of urban mobility. But the rapid urbanization is not accompanied with systematic planning of urban form and other infrastructural facilities. In most of the cities ,public transport is inadequate and the congestion is severe. Despite massive infusion of investment the transportation crisis in metropolitan areas has been growing. Traffic congestion,air pollution,urban sprawl and the need for energy conservation provide or improve the mass transit system in order to alleviate these problems.

In this context of urban transportation planning, mass transportation of passengers may be carried out by means of rapid rail transit i.e. MRTS (Mass Rapid Transit System) and bus transport system. But in metropolitan areas where traffic density is at very high level, bus transport fails to cater the high demand. Severe congestion is the chronic disease for these metropolitan cities. Rapid Rail Transit(RRT) can bring the new life to the decaying urban areas.

With the introduction of this new mode(RRT), the travel pattern of public transport users will change considerably. So there is a need to plan for the transport integration facilities at all MRTS stations. The MRTS will serve the trunk routes with higher passenger demand and bus services will feed to the MRT system. Though the demand can be predicted accurately, poor planning strategies and inefficient operational methodoligies are the cause of heavy losses incurred by bus operators and the public sector.

The cost of rerouting the buses within the existing network involves little investment but can improve the performance drastically. Among the many issues like route design,bus allocation and scheduling,crew scheduling, maintenance etc., the planning of feeder routes and scheduling of buses can be considered as a primary one as the optimal routes influence the design of other aspects of operation.

1.2 ROLE OF MRTS

Rail transit is a major solution to the growing transportation problems in large metropolitan areas. It carries the bulk of passengers in large metropolitan areas. A larger and rising percentage of rail trips is made up of work trips to and from the CBD. Thus it makes a great contribution to the relief of peak hour congestion in urban areas. This new mode with higher performance such as high capacity,higher operating speeds, high reliability, less transfer time, has higher passenger attraction. It provides the higher level of service with lower operating cost and give the smooth riding comfort. It will help to increase the real estate values. From the saving of energy and wear point of view , it is the better alternative than the bus transport.

1.3 Problem of MRTS

The introduction of this new mode requires the high investment cost and costly exclusive right of way. Longer implementation time associated with disruption of corridor is one of the major problem of this transit system. So a threshold minimum traffic density and long trip lengths are necessary for economic feasibility to adopt this rapid transit system. It serves fixed metropolitan areas such as downtown areas and thus needs off line feeder and transfer services. The failure of this system will not only cause heavy losses but also

increases congestion by bringing more people into already crowed urban areas.

1.4 Present Trend in Public Transport at The Metropolitan Cities in India

The trend of urbanization in India has been accelerating, especially in the last three decades. Transport demand in major metropolitan cities has increased considerably over the years and will be around 1.5 to 2 times by 2001 as compared to 1981 levels. The Table 1.1 will give the clear picture of the present trend in four major metropolitan cities.

Table 1.1: Annual Growth Trend of Metropolitan Cities

City	Population Growth Rate (%)	Motor Vehicle Growth Rate (%)	Trips (lakhs)	Passengers carried (million)
Calcutta	2.3	3.98	36	331.37(CSTC)
Bombay	3.5	5.82	23	1549.55(BEST)
Delhi	4.7	8.33	76	1000.26(DTC)
Madras	3.5	14.69	78	905.54(PTC)

Source: Indian Road Congress Journal, 1992 (Paper no. 414)

As the city grows , there is a shift in modal patterns. Table 1.2 shows the trend in shift in modes in Delhi and Bombay. The Table gives the picture that there is a bias to public transport as the city is expanding. In Delhi 36% of the trips in 1957 was performed by cycles but whereas by 1981 the transit ridership increased from 22.4% to 59.7%.

Delhi is a nationally important city and one of the most rapidly growing city in India. The population and vehicle growth trend are alarmingly increasing. The public transportation facilities available in Delhi despite the increase in fleet strength and improvement in productivity levels of DTC are proving to be inadequate in catering to the growing transportation demand.

As a result, the traffic and transport problems are aggravating and manifesting in increased traffic congestion on roads, delays at intersections and congestion and overcrowing

Table 1.2: Changing Patterns of Transportation at Delhi and Bombay

City	Delhi		Bombay	
	1957	1981	1971	1986
Total trips(lakhs)	11.3	39	56.3	113.4
% share of mode				
Rail	0.4	1.6	41.5	33.4
Bus	22.4	59.7	41.5	33.9
Car	10.1	5.5	6.1	7.6
2-Wheeler	1.0	11.1	1.5	3.6
3-Wheeler	7.8	0.8	-	11.7
Taxi	4.4	0.2	9.2	9.8
Cycle	36.0	17.0	NA	NA
Others	17.9	4.1	-	-

Source:Proc. of the National Conference on Trans. Sys. and Studies

in public transport buses with consequent deterioration in road traffic safety and environmental condition. The mobility levels study conducted by CRRI suggests that commuters in general, are dissatisfied with the reliability, comfort and convenience. Hence the new system of transportation (Mass Rapid Transit System) seems to rescue the city from the present problem.

1.5 Review of Literature

The success of MRTS system depends on the proper planning and design of feeder routes. scheduling and operational reliability. But except some recent efforts, general practice is based on intuition and experiences rather than optimization or proper modeling.

Tsamboulas, Gollias and Marios (1992) analyzed the behaviour of metro- users in choosing their access mode to a metro station. They used population segmentation approach by multinomial probit model. Doi and Allen (1986) had done a time series analysis of monthly ridership for an MRT (Mass Rapid Transit System). Schabas (1988) studied the qualitative analysis of rapid transit alignment of alternatives so that a coordinated bus and rapid transit system could offer commuters substantial time and cost savings. Wirasinghe (1986) studied the rail line length required so that it will minimize the total transporta-

tion (both user and customer) costs and the necessary threshold demand satisfied. Guillot (1984) investigated the bus transit interface with light rail transit in Western Canada. New LRT (Light Rail Transit) services usually call for routing of feeder buses at the outer rail stations. So there is necessity for early planning for revisions of an existing network. A.C.Sarna et al. (1992) studied the different alter- natives for the planning of mass rapid transit system in Delhi. Marwah B.R.(1994) Developed the study methodology for planning of feeder bus routes for mass rapid transit system in Delhi. Halder D.K. and Mazumdar A. (1980) developed a method for selecting optimum number of stations for a rapid transit line. Hunt (1979) carried out the performance study on rapid transit system. Rubin (1975) developed routing algorithms to find out the optimal routes for cars in the urban rapid transit system.

Tiang (1983) surveyed the different planning methods for urban bus routes. He identified five Approaches :

1) Manual
2) Market Analysis Project (MAP)
3) Systems Analysis
4) Systems Analysis with interactive graphics and
5) Mathematical.

Furth (1986) and Tsao et al. (1983) studied on the optimal zonal route design for transit corridors. Newell (1979) developed a methodology for designing of minimum cost bus route serving a multiple origin and destination trip distribution. A methodology for vehicle routing with stochastic demand properties was developed by Gilbert and Trudeau (1989). Srivastava, N.S. (1984) worked on the optimization of bus transport at Aurangabad region. An interactive modeling approach to solve the practical problem of bus route network design was developed by Budhesuden, Ranjithan and singh (1987). A heuristic algorithm was developed by Dhingra(1980) for the structuring of a route network. Marwah and Patnaik(1984) have developed a method in which selection of routes and frequencies are done simultaneously for Kanpur bus transportation.

An analytical queuing model used for predicting passenger delay in a rapid transit station was developed by Hall, R.W. (1987). Again Vuchic and Kikuchi (1982) analyzes the optimum number of stops and the optimal vehicle policy for operation of a transit

route.

Salzborn(1980) advocated some rules for scheduling of bus system consisting of inter-town route linking of a string of interchanges. Satit(1986) presented the development and evaluation of alternative bus dispatching and route policies for an exclusive bus lane. Nuttle(1987) worked the comparison of heuristics for school bus scheduling problem. Gallio et al.(1982) solved the large scale bus driver scheduling problem with a relaxation. Kikuchi and Asce(1984) developed a methodology for scheduling of demand responsive transit vehicles. Patel and Saha(1980) discussed the heuristics for the construction of model to solve the variable schedule of fleet size subject to maintenance constraint. Schonfeld(1991) developed the analytic models for optimizing bus services with time dependence rather than using numerical methods (Morlok and Viton, 1984).

1.6 Objective of The Study

From the above discussion it is clear that there is a need for a well planned feeder bus route network for the successful operation of MRTS.Thus, to design an efficient bus network, the study is carried out with following objectives :

a. Generation of efficient feeder bus route network with the help of interactive graphics.

b. Allocation of buses on various designed routes and carry out optimal scheduling.

An interactive graphic system is an on line computer system to aid the user's experience so that more number of alternatives can be tested. An efficient and effective transit network can be generated with the interactive graphic system.

1.7 Resume

The following chapters discuss the subjects given below.

Chapter 2 describes the problem and solution methodology.

Chapter 3 consists of detailed study methodology. Different models and submodels are discussed.

Chapter 4 deals with the case study analysis. The models are tried to implement for the city of Delhi.

Finally, Chapter 5 contains the conclusion and scope for future work.

Chapter 2

Solution Methodology

2.1 The Problem

Economy in operation,reliable and adequate level of service to the users should be the primary objective of any transport management policies. The efficient way of operating the MRTS is to develop the transport integration facilities i.e. feeder bus services, parking lots e.t.c. This should be done with the minimum amount of resources. In order to achieve the above objective, proper planning methodology should be evolved. Here the following aspects are studied :

a. structuring of routes in order to meet the demand in an effective manner.

b. Determination of optimum schedules with the minimum resource.

2.2 Methodologies

Today's transit planning and development is carried out in adhoc manner. Any intuitive approach to the transit network planning problem cannot provide reliable answers. Various approaches are used to the vehicle routing and scheduling problem. Fig 2.1 displays a general classification of these approaches. The circular nature of the program highlights the fact that combinations of these three approaches have also been used. The four general approaches are outlined in the following section.

2.2.1 Heuristic Approaches

Due to the complex combinatorial nature of the vehicle and scheduling problem heuristic techniques dominate the solution procedure. Generally, in this approach a large route (usu-

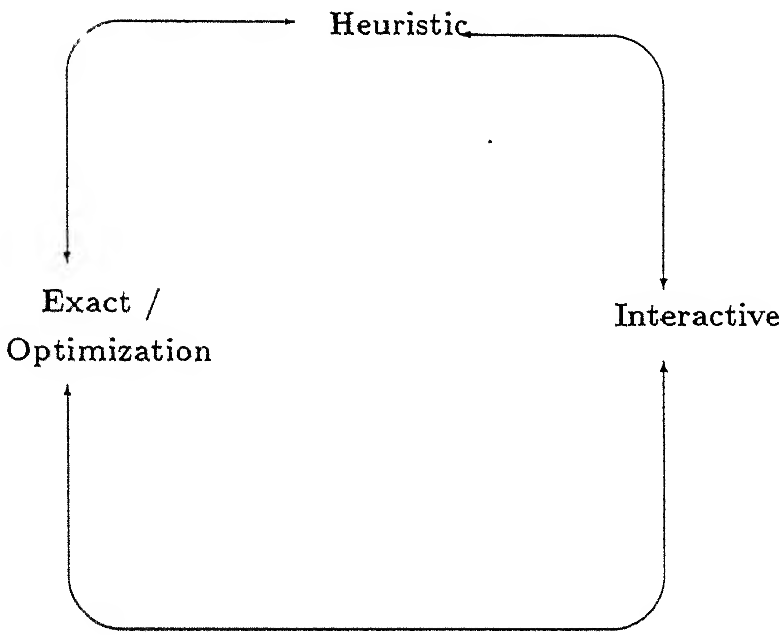


Figure 2.1: Methdologies to VRS problems

ally infeasible) is built up and then this large route is partitioned into a smaller number feasible routes. Four methodologies are used in this category.

a. Cluster-first, route second procedures (Gillete and Miller, 1974)

b. Route-first,cluster second procedures (Assad and Bodin, 1983)

c. Savings, or insertion procedures (Clarke and Wright, 1964)

d. Exchange, or improvement procedures (Lin and Kernighan, 1973)

The difficulties of this approach is that vehicles with different capacities can not be easily incorporated. According to the complexity of the problem, the computational time increases dramatically.

2.2.2 Exact or Optimal Approaches

Exact or optimal solution procedures are always desirable. But unfortunately such procedures have often been too computationally complex to solve realistically sized VRS problem, Mathematical optimization or mathematical programming approaches generate new bus routes and unconventional network by optimizing an objective function. But this technique has a limitation of optimizing an objective function. Two different branch and bound algorithms (Christofides, Mingozzi and Tothi, 1981) have been derived. The first uses the dynamic programming to obtain the effective lower bounds whereas the second uses an improved Langrangian relaxation procedure to optimally solve small problems. The main difficulty with all exact procedures is the huge number of constraints and variables needed to represent even the basic VRS problem and their adverse effect on computational time and computer storage space.

2.2.3 Interactive Approaches

The third solution strategy is the most simplistic. But in some respects it may be the most powerful of all the strategies. This method involves either a simulation, or some kind of graphics capability to aid the decision maker. Graphics give visual aids so that routes can be generated initially, redesigned, or finally verified as to the satisfactory level of the user (Doll, 1980). These Methods are merely aids to the decision maker, who still must use some intuitive methods to solve the problem. The obvious drawback of this approach is

the skill and ability of the decision maker, particularly as the problem size and complexity increases.

2.2.4 Combination Approaches

Combinations of the three strategies in fig 2.1 have proven very popular. Several studies combining mathematical programming and heuristic techniques (Stewart, 1981) have performed well. A globally optimal solutions may not be guaranteed but very good solutions are expected. Some studies (Cullen, Jarvis and Ratiff, 1981) were made involving graphics and heuristic procedures. Good optimal solutions were being achieved. The difficulty would be to consistently ensure very good or near optimal solutions.

For analyzing the VRS solution methodologies, generally two performance criteria are to be considered, 1) generizability i.e. to include the different extensions such as impact of hired modes, multiple depots, time windows, multiple type of vehicles, capacity limits, demand variability, multiple vehicle speeds etc. 2) accuracy of the solution, or nearness to an optimal solution. Criterion 1 measures the usefulness of the method and criterion 2 represents the possible cost savings due to decreased vehicle operating expences, better customer service, and improved fleet investment.

The exact solution procedures fail to handle the present problem of large network due to the complexity in size and the intricate nature of factors involved and also it is theoretically too rigorous to use. For the present study, heuristic procedure, based on experience with interactive graphics to aid the planner in decision making are being used.

Chapter 3

Model Development

3.1 Introduction

The purpose of this study is to propose a method such that selection of routes is done for network and the assignment of the frequency is done thereafter. The method suggested is a combination of heuristic search and the programming model. The graphic representation of the network is a powerful capability of the program which help user's experience in selection of routes and analysis. The method is easily applicable to real size network and involves lesser computation time.

3.2 Overview of The Model

The broad study methodology is given in Fig 3.1. The proposed model consists of the following submodels.

a. Estimation of feeder bus passenger demand for each MRTS station.

b. Routing submodel for generation of feeder routes for each MRTS station.

c. Scheduling submodel to allocate trips/buses for each feeder route.

Important aspects of the various stages of methodology are described in the following section.

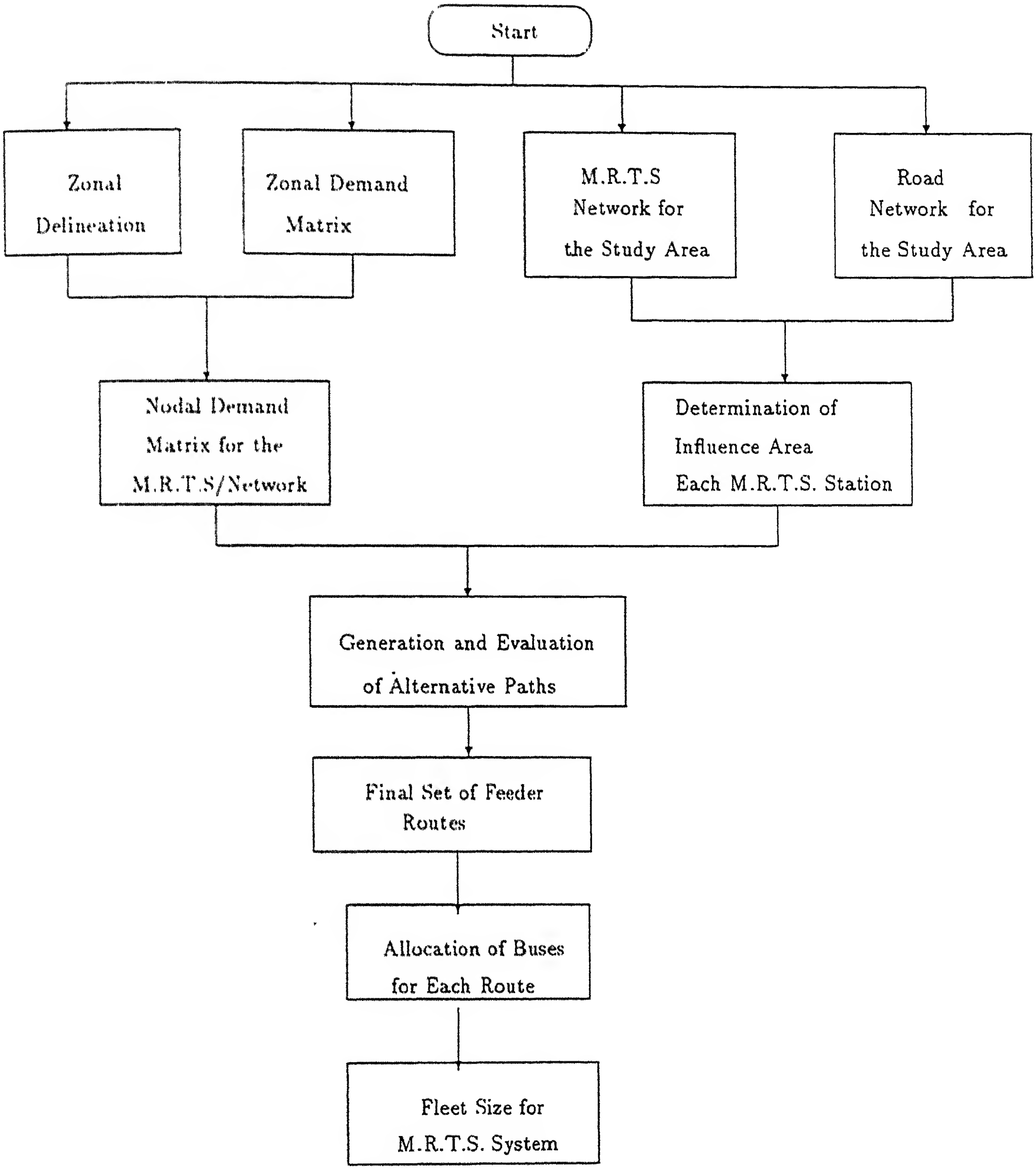


Figure 3.1: Methodology for planning of feeder bus routes

3.3 Estimation of Total Passenger Demand Matrix For Each MRTS Station

The approach used for generating feeder bus passenger demand matrix for each MRTS station is shown in fig 3.3.

a. The distribution of demand at the zonal level is available. This is an aggregated demand matrix at zonal level. For planning of feeder routes we have to find out the demand pattern at the nodal level. Zonal distribution,zonal public transport demand pattern and the connectivity matrix is given. The element of the connectivity matrix is such that
if a zone uses MRTS then

zone[i].connect=1; i.e. equal to 1 if zone i is connected to MRTS station.

else

zone[i].connect=0; otherwise.

Zonal MRTS demand matrix is found out by

zonal_MRTS_demand[i][j] = Zonal_demand[i][j]*connect[i][j].

and delete the zones which are not using MRTS, from the zonal MRTS demand matrix.

b. As the zonal MRTS demand matrix is not sufficient for the planning, nodal demand matrix needs to be estimated. Nodal distributions in the zones are given. From the zonal MRTS demand matrix, we know

$$\sum t_{ij} = p_i;$$

for all j

$$\sum t_{ij} = a_j;$$

for all i

where ,

t_{ij} is the trips between the zone i and zone j and

p_i is the total number of productions at zone i and

a_j is the total number of attractions at zone j.

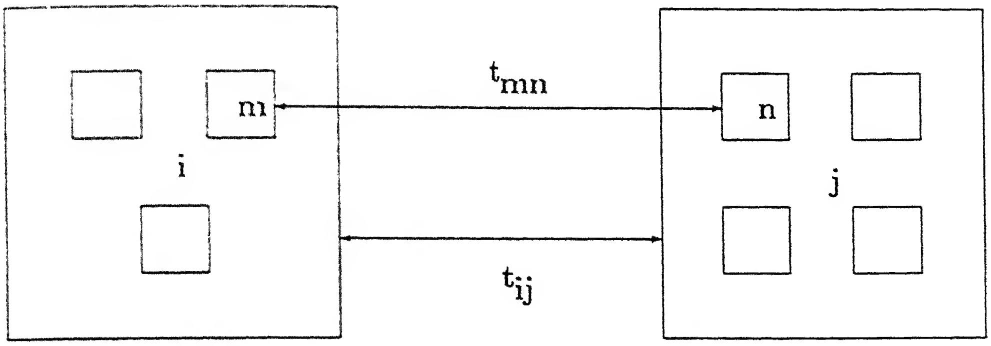


Figure 3.2: Estimation of Zonal to Nodal demand matrix

Assume there is m number of nodes in zone i and n number of nodes in zone j (Fig 3.2). Determine the share of demand for each of the node with respect to the demand of the zone in which it lies.

$$\text{i.e. } \sum prod_m = p_i$$
$$\sum attr_n = a_j$$

where ,

$prod_m$ denotes the total number of productions for node m at zone i,

and $attr_n$ denotes the total number of attractions for node n at zone j.

Production and attraction for the m^{th} node in zone i and n^{th} node in zone j can be determined as follows.

$$prod_m = weight_m \ / \sum weight_m * p_i$$
$$attr_n = weight_n \ / \sum weight_n * a_j$$

Then production share for m_{th} node in zone i and attraction share for n_{th} node in zone j are

$$\text{prod\_}share_m = prod_m \ / \ p_i \ ;$$
$$\text{attr\_}share_n = attr_n / a_j \text{i} \ ;$$

where,

prod_$share_m$ is the share of production in percent for node m at zone i. and attr_$share_n$ is the share of attraction in percent for node n at zone j.

Now, nodal MRTS demand matrix is estimated by

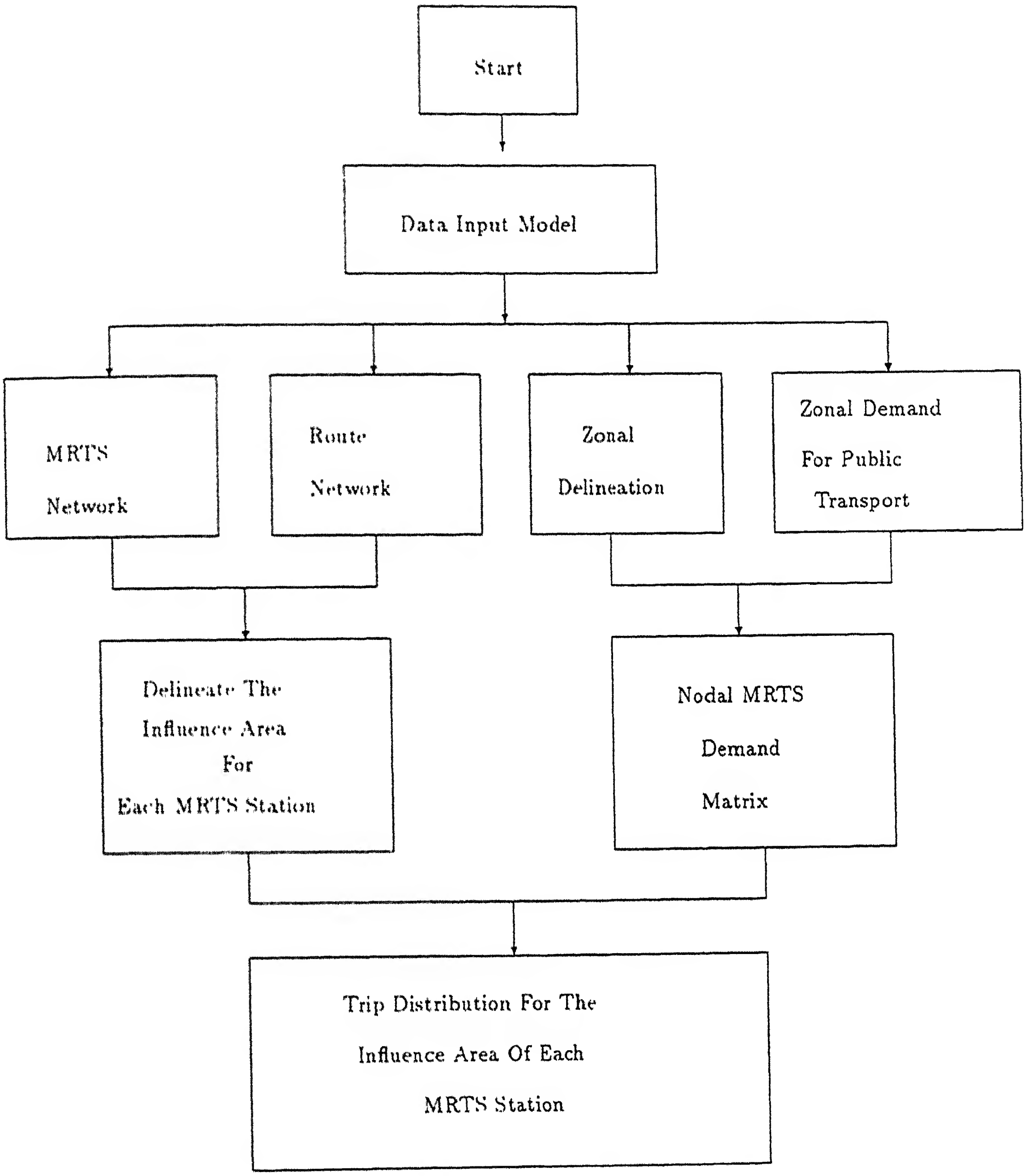


Figure 3.3: Estimation of nodal demand matrix for each MRTS station

$$t_{mn} = t_{ij} * \text{prod\_share}_m * \text{attr\_share}_n$$

where, t_{mn} denotes the number of trips between node m and node n, so that

$$\sum_{mn} t_{mn} = t_{ij}$$

c. Delineate the influence area for each MRTS station

For an internodal demand that is to use a MRTS system, identify the MRTS through which the movement will take place. To identify the station, the following procedure is used. Determine the shortest paths from node n1 to node n2 to the nearby MRTS stations s1 and s2. That particular MRTS station which has the shortest path to reach a node $n1$ and $n2$ will be utilized. The transfer between $n1$ and $n2$ can occur by

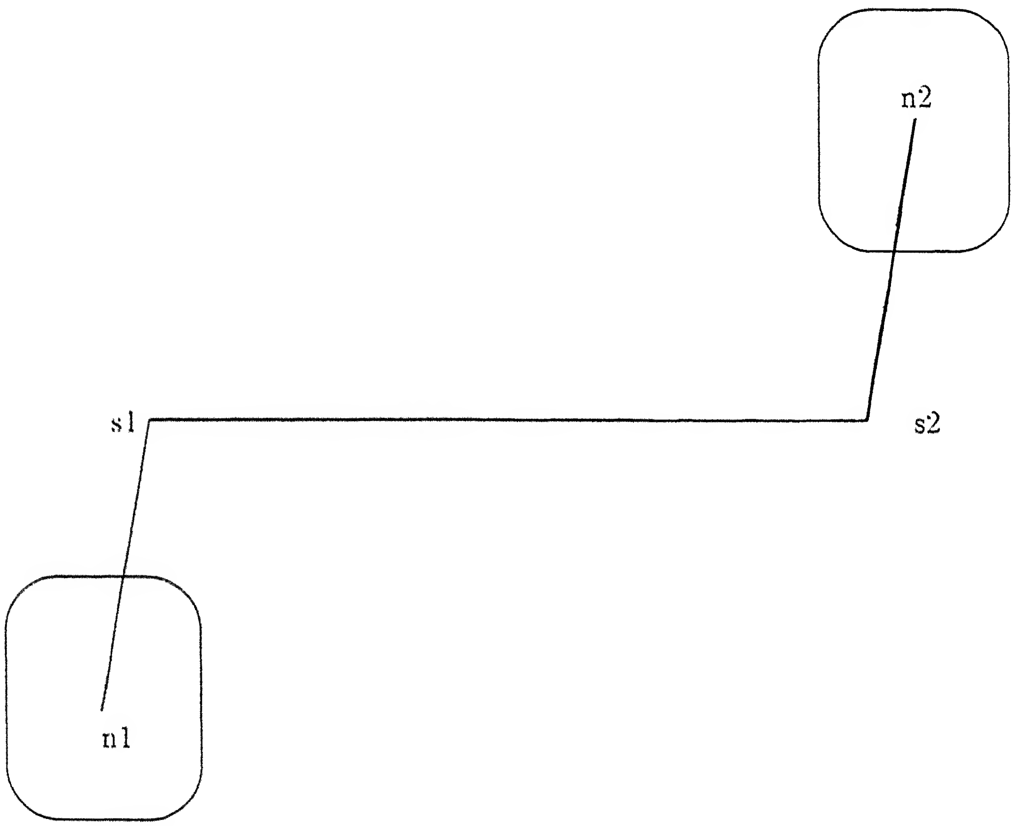


Figure 3.4: Delineation of zones

1. i) From $n1$ to $s1$ by feeder bus system or by walk.

ii) From s1 to s2 by train.

iii) From s2 to n2 by feeder bus system or by walk.

2. From $n1$ to $n2$ directly by bus transit system.

The travel times along the following alternative paths are determined. If the travel time on the MRTS/road system is less than the travel time alone on the road system, then the node $n1$ will come under the influence area of MRTS station $s1$ and node $n2$ will come under that of MRTS station $s2$. After doing this whole operation,we will get the influence area for each MRTS station.

3.4 Description of Routing Model

3.4.1 Introduction

In the proposed model, Fig 3.7, the routes are built up based upon the criteria of accessibility so that maximum number of nodes being connected to the MRTS station as well as the demand satisfied. The routes should be planned so that the generalized travel time is minimized and the route lengths are within specified limit. Alternative paths are generated taking care that the deviated distance of these paths should not be greater than 1.5 times the previous distance. A large set of feasible bus routes are generated ,evaluated so that the various nodes within the influence area of a MRTS station are served in an optimum way. Selection of routes is done thereafter. The various submodels involved to achieve this objective are described in the following sections. The routing submodel which is going to be discussed is shown in Fig 3.4.

3.4.2 Patterns of Feeder Routes

Feeder routes that may be generated are of the following three types.

a. Radial pattern (Fig 3.5a) : This pattern operates between a major traffic generator on the road network and MRTS station. Operation of this pattern involves only boarding or alighting operation. The route having a higher operating speed is preferred on high demand corridor.

b. Ring pattern (Fig 3.5b) : In this route pattern the route originates and terminates at the MRTS station. During operation, both boarding and alighting take place and thereby

reducing the operating speed. It could be preferred over short length and is simple to operate.

c. MRTS corridors connection pattern (Fig 3.6) : The feeder route has two MRTS stations as the terminals. This pattern may be adopted when stations of two radial MRTS corridors are close and have overlapping influence zones. A major advantage of this pattern is that it reduces transfers on MRTS system in the CBD area. Each direction of operation involves boarding and alighting of passengers.

3.4.3 Data Input Submodel

This submodel reads the following inputs.

i) MRTS/road network for the study area.

ii) Trip distribution matrix for the influence area of an MRTS station.

iii) Spatial distribution of nodes in the influence area.

iv) distance matrix for the study area.

v) Details of links in the study area.

vi) Names of the different nodes and MRTS station for presentation of graphic display.

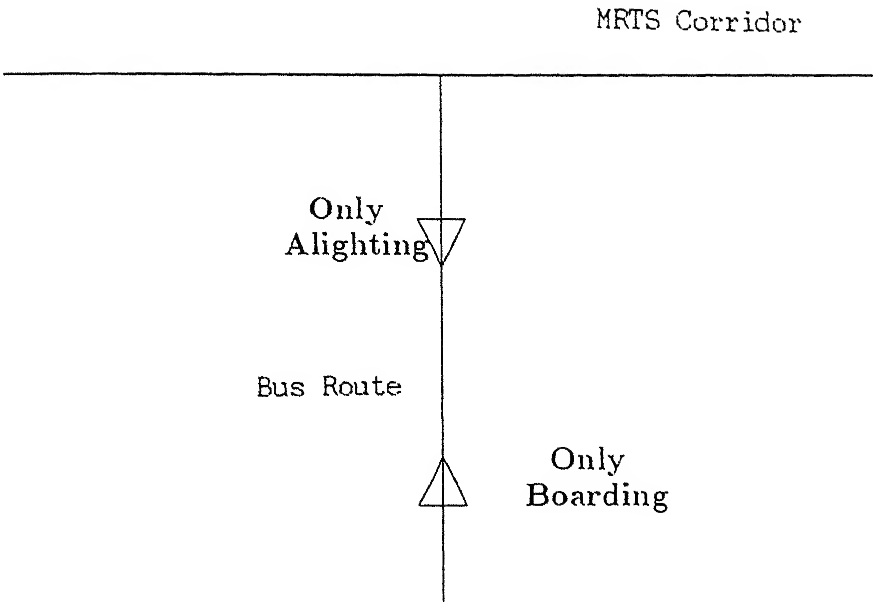
3.4.4 Terminal Identification Submodel

Generally the nodes with significant traffic demand are treated as terminals in the bus transit system and are connected through built up paths. Usually this node, termed as major traffic generator is identified as node whose production is greater than 1.5 times of the average nodal production of the network. For the feeder bus route network, the objective is to provide accessibility to all nodes in the influence area of a MRTS station as well as the minimization of the number of feeder bus routes. The approach adopted consists of

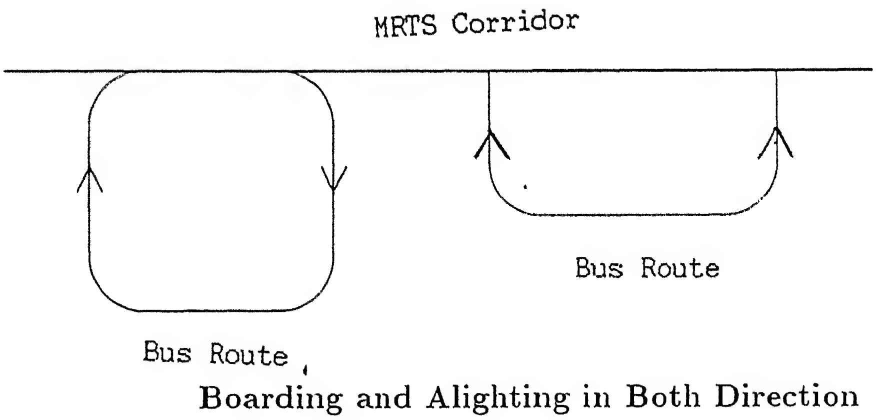
a. The farthest node from the influence area of a MRTS station should be identified. This node will provide accessibility to a number of other nodes also.

b. The node should have some significant traffic demand.

Using the above two criteria, a terminal is identified. The other terminal of the route is the MRTS station under investigation. If the influence zone of two adjoining corridor are overlapping, a feeder route can be planned between two MRTS stations.

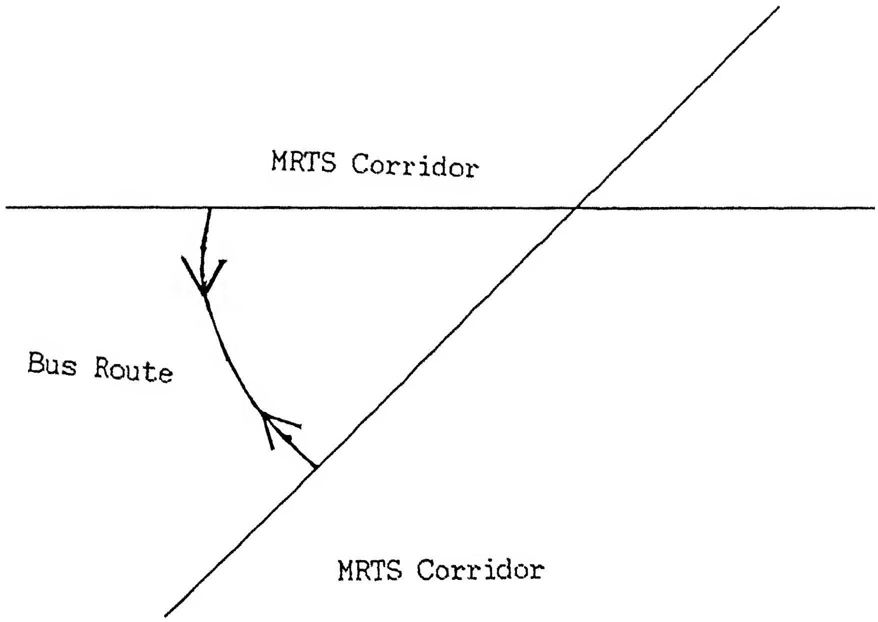


(a)



(b)

Figure 3.5: Radial and ring pattern of routes



Boarding and Alighting in Both Direction

Figure 3.6: MRTS corridors connection patterns of routes

The generated alternative routes from this terminal are evaluated. After selecting the final path for this terminal, another terminal from the unconnected nodes is identified and the above procedure will go on repeating until most of the nodes in the influence area are covered by the generated feeder bus routes.

3.4.5 Generation of Route Path

Between the terminal and the MRTS station, a number of feeder routes are generated as follows.(a).Generation of shortest path :
The shortest path between the selected pair of terminals is generated as first alternative. The program uses the Floyd's algorithm for generation of shortest path. The algorithm is described below.

Before presenting the algorithm, the notations are as follows.
Number the vertices $1, 2, ..., n$. Let d_{ij}^m denote the length of a shortest path from vertex i to vertex j, where only the first m vertices are allowed to be intermediate vertices. (an intermediate vertex is any vertex in the path except the initial or terminal vertex in the path). If no such path exists then $d_{ij}^m = \infty$. From this definition of d_{ij}^m, it follows that d_{ij}^0 denotes the length of a shortest path from i to j that uses no intermediate vertices, i.e., the length of the shortest arc from i to j (if such an arc exists). Let $d_{ij}^0 = 0$ for all vertices i. Furthermore, d_{ij}^n represents the length of a shortest path from i to j. Let D^m denote the n by n matrix whose i, jth element is d_{ij}^m. Ultimately we wish to determine D^n the matrix of shortest path lengths. The Floyd shortest path algorithm starts with D^0 and calculates D^1 from D^0 . Next the Floyd shortest path algorithm calculates D^2 from D^1. This process is repeated until D^n is calculated from D^{n-1}. p_{ij} represents the path, intermediate vertex between vertex i and vertex j. Whenever any intermediate node is included the path matrix p_{ij} is updated as follows.
Step 1 :

Number the vertices of the network $1, 2, ..., n$. Determine the matrix D^0 whose i, j th element equals the length of the shortest arc from vertex i to vertex j if any. If no such arc exists then $d_{ij}^0 = \infty$.

Let $d_{ii}^0 = 0$ for i.

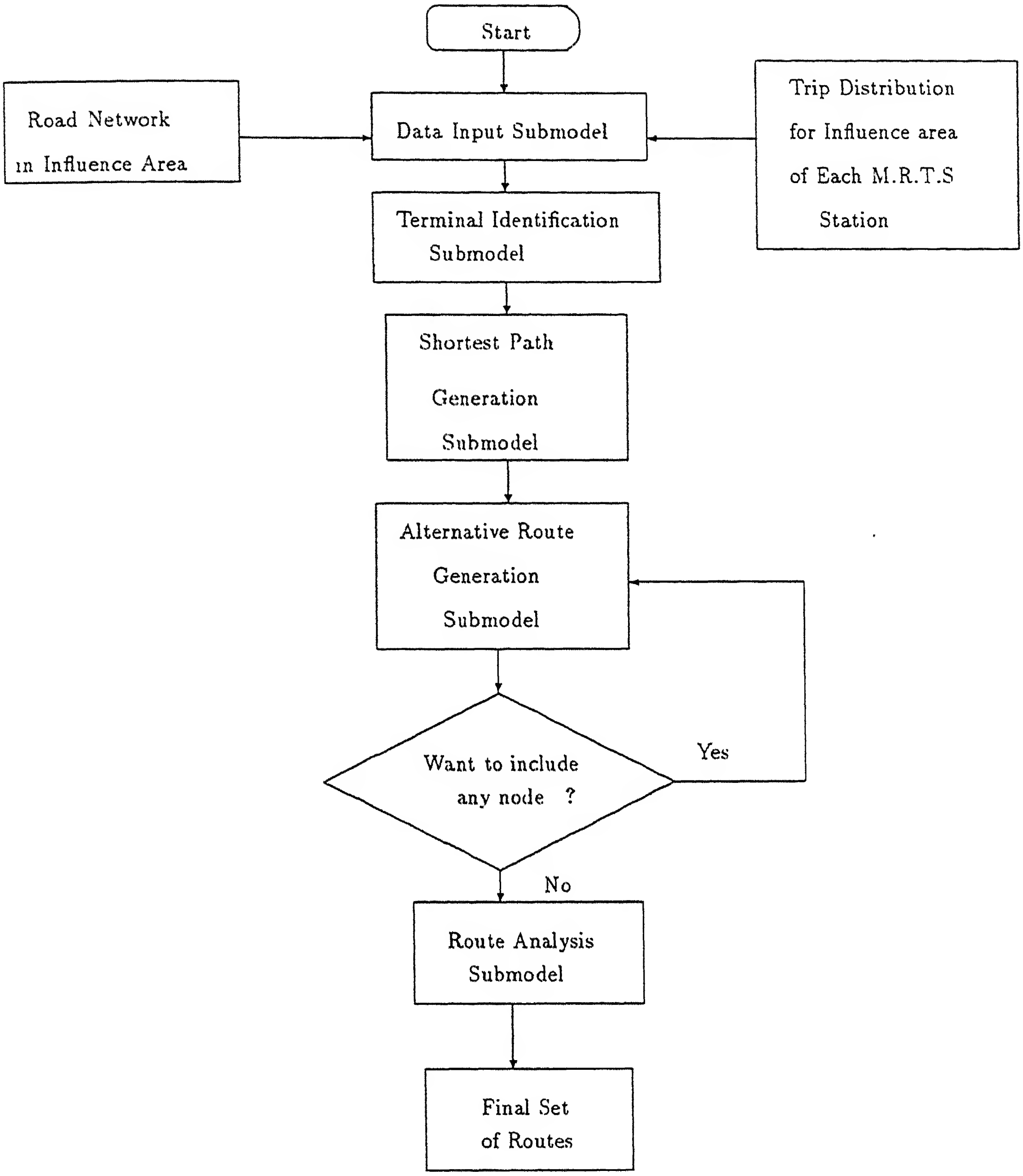


Figure 3.7: Routing Submodel

$$p_{ij} = i .$$

Step 2 :

For $m = 1, 2, ...n$, successively determine the elements of D^m from the elements of D^{m-1} using the following recursive formula

$$d_{ij}^m = \min \{d_{ij}^{m-1}, d_{im}^{m-1} + d_{mj}^{m-1}\}$$

if the later value is chosen, then change p_{ij} to $p_{k+1,j}$.

As each element is determined, record the path that it presents. Upon termination, the i, jth element of matrix D^n represents the length of a shortest path from vertex i to vertex j. The shortest path is generated between the terminal node to MRTS station.

b. Generation of alternative path

After generating the shortest path, a number of alternative paths are also generated such that the deviated distance is not greater than 1.5 times the previous distance and the total route length should be within the specified limit (say less than twice the shortest path). Though these alternatives have the longer length than the shortest one, they also provide more accessibility to other unconnected nodes. The alternative routes are generated in the following way.

a. A node is identified which is connected to any two adjacent nodes lying in the shortest path

b. The distance between the two nodes in the shortest path passing through the identified node is calculated. If this distance is less than 1.5 times the distance between the two nodes in the shortest path and if the total route length is less than twice the length of shortest path, then this path is considered as an alternative one.

This process is repeated until all the nodes are examined for the inclusion in the shortest path. Again if there is any important nodes to be considered, then the alternative is generated by adding two shortest paths, one from the start node (road terminal) to the intermediate node to be considered and the other one from the intermediate node to be considered to the MRTS station. In this way a set of feasible alternatives are generated between the selected terminals for further analysis and selection.

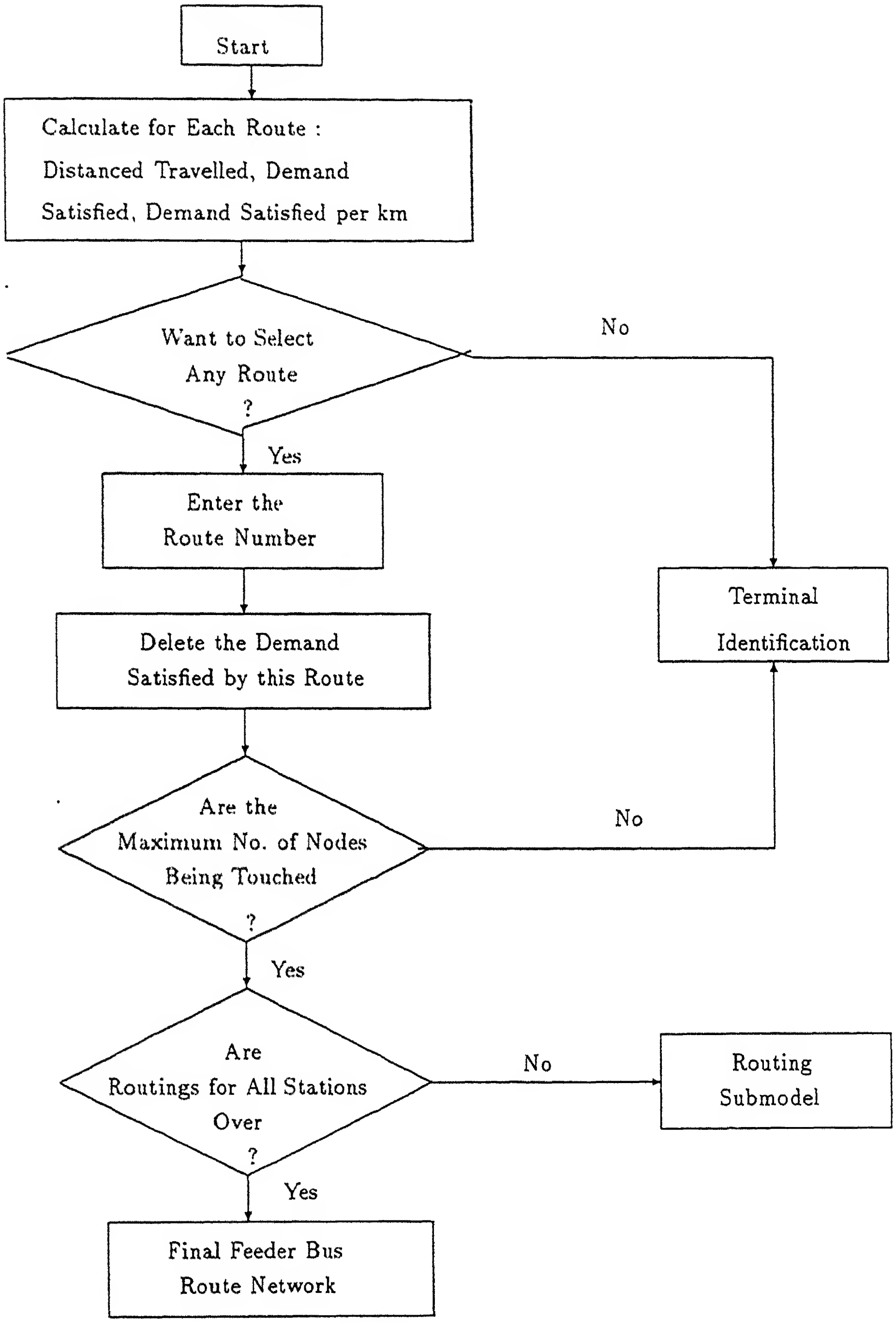


Figure 3.8: Route analysis submodel

Evaluation of alternative path

The route analysis submodel is presented in Fig 3.8. Various feasible generated alternatives are compared with the following criteria.

$$\text{Demand\_satisfied} = \sum^{allnodesinthepath} \text{nodal demand}[i]$$

$$\text{Route\_length} = \sum \text{length of the links in the generated path}$$

$$\text{Demand\_satisfied\_per\_km} = \text{Demand\_satisfied} / \text{Route\_length}.$$

Demand satisfied per unit length referred to as Route utilization parameter. This is used for evaluation of alternative generated route. The routes are to be selected with highest level of demand satisfaction. For last couple of nodes the route is to be selected on the basis of accessibility to more untouched nodes though the demand satisfied per unit length for this route is less.

Once a route is selected, the demand of the different nodes on the selected routes are deleted from the travel demand matrix and again another terminal out of unconnected nodes within the influence area for the MRTS station is identified. The routes are generated and evaluated. The process is repeated until maximum number of nodes being touched. Graphical representation further aids the user in analyzing and selection of routes.

3.5 Description of Scheduling Model

3.5.1 Introduction

In this model, a heuristic algorithm is developed for determination of the optimal allocation of buses and the optimal headway for the operation of buses on the various feeder routes of MRTS /road network. The model (Fig 3.9) schedules the buses for any period of study under the different desired level of service. It is assumed during scheduling process that a node within a particular length (say half a kilometer)from MRTS station will not use the feeder services. The model described is shown in Fig 3.5. The model operates as follows.

3.5.2 Model inputs

This submodel reads the following inputs.

i) The path of the generated routes.

ii) The nodes in the influence area of each MRTS station.

iii) The estimated demand from nodes to MRTS station which will use the feeder routes.

iv) The lengths of the various links of the network.

3.5.3 Estimation of The Operating Flow Characteristics

The passenger flows along the various links are to be determined for finding out the different flow characteristics along a route.The passenger flows along a route from terminal to MRTS station are gradually increasing due to the boarding of passengers. Opposite will be the case when the flow is from station to terminal due to alighting of passengers. Hence the link closest to MRTS station has the highest passenger link flow and the link nearer to the terminal has the lowest passenger link flow.

Let there be n nodes along a feeder route where nth node is the MRTS station. The demand from a node i to the MRTS station is given by nodal_station _demand[i,n]. The passenger flow on any link is calculated by adding up the flows on the links that are already passed through to come to this link. This is denoted as P_L_F(i,n).

$$\text{P\_L\_F} = \sum \text{nodal\_station\_demand}[i,n]$$

Because of the wide variation of link flows, the following two parameters are estimated.

i) Maximum link flow :

This is maximum of the flow on the links. Due to the gradual increase of link flows, the maximum flow will be the flow on the link adjacent to the MRTS station (may be connected to the station/half a km away from the station). This represents the total number of passengers served along the route. This is estimated as max_link_flow.

$$\text{max\_link\_flow} = \sum_{i=1}^{n} Nodal\_station\_Demand[i,n]$$

or

$$\text{max\_link\_flow} = \text{P\_L\_F}(n-1,n)$$

ii) Average link flow :

Variation of passenger flows on the various links is taken care of by this parameter. This is of considerable importance in determining the trips. The mean of all link flows will give the equal weightages to all links irrespective of their length. The design will not be meaningful based on the average link flow. To have a more realistic design, a parameter

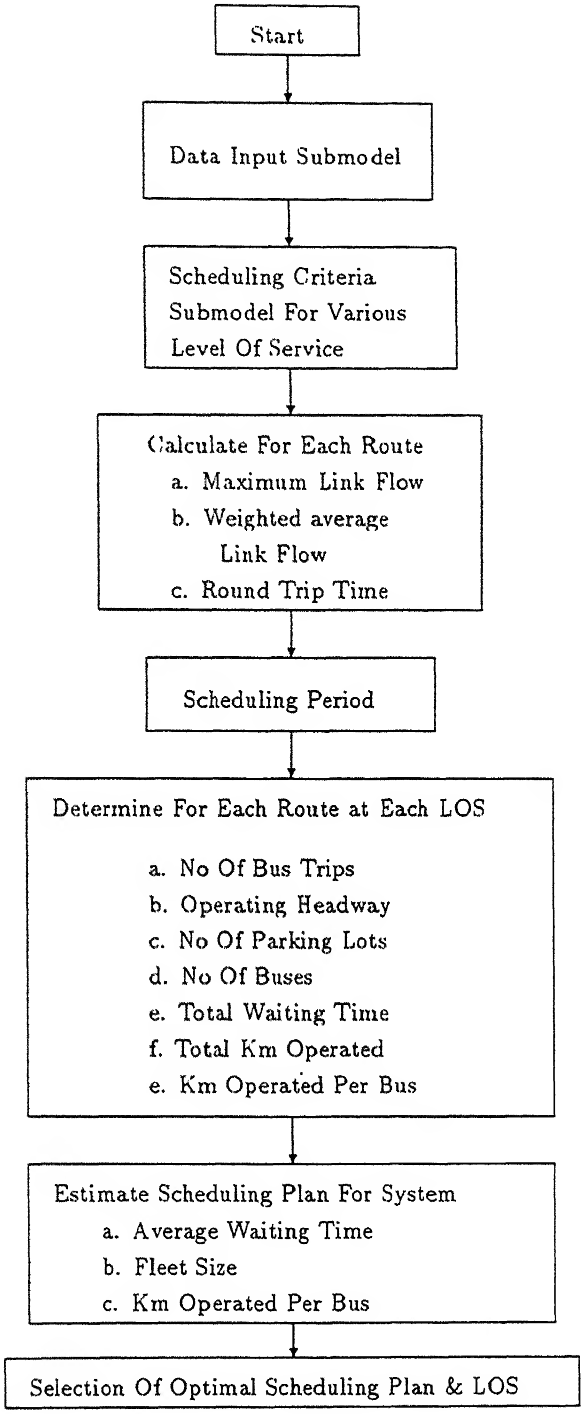


Figure 3.9: Scheduling Submodel

called weighted average link flow(W_A_L_F) where the due weightage is given to the link length variation, is used. This is determined as follows

$$W\_A\_L\_F = P\_L\_F\ (1,1+1) * \text{link length}\ (1) / \sum^{1} \text{link length}\ (i)$$

3.5.4 Estimation of Bus Trips

Bus trips should be calculated for different level of service condition. Level of service (LOS) is defined with respect to the bus loads (percentage bus full). For a desired LOS,average bus loads and maximum bus loads are assigned. Bus trips are being calculated by

Trips = link_flow / Bus_load(LOS)

The number of bus trips(N_Trips) for the operation of a route at any period of design is based on average bus load condition. i.e.

Bus_trips = Weighted average link flow / Average bus load

3.5.5 Estimation of Headway for Operation

The headway for the route is the successive time difference between the the two buses for operation at a terminal. The headway is calculated as

Required_headway = Period_time/Bus_trips

where period time is the period of scheduling(i.e. Peak period/Off peak period). From the practical point of view, this should be restricted to a certain minimum and maximum values for the operation. If the headway is too large or too small, it does not provide the desired service for which the system is being planned. For the proposed system, the minimum and maximum values of the headway are limited to 3 and 20 minutes. Knowing the desired headway with their constraint values, the actual headway for which the system is to be operated is determined.

Headway_operated = Max[3,Required_headway]

or

= min[20,Required_headway]

3.5.6 Estimation of Round Trip Time For A Route

The round trip time for a route is that time between starting of the transit units from one terminal and the restarting of the same transit units from the same terminal.The round trip for a route includes running time in each direction, total halt time of the buses at the stops and the lay over time at the MRTS station and road terminal.

The running time depends on the operating speed of the vehicle in the area of operation. The halt time of the buses i.e. loading and unloading time of passengers,depends on the number of passengers boarding and alighting at the stops and the number of stops along a route. For the study purpose, average halt time is taken as about 30 seconds. A minimum lay over time of 5 minutes is to be provided on the MRTS station and at the route terminal.

The total round trip time for a bus is estimated as

Round_trip_time=2*(Running_time+Halt_time+Lay_over_time).

3.5.7 Estimation of Buses For Operation in A Certain Period

The number of bus trips in each direction for the scheduling period (peak period of 3 hour duration/off peak period of 6 hour duration) are estimated as

Design_bus_trips = scheduling period/headway_operated.

The number of buses to be operated along a route are estimated as

No_of_buses = Round_trip_time/headway_operated.

3.5.8 Determination of Number of Parking Lots at MRTS Station For A Route

This can be calculated as

No_of_parking_lots = Lay_over_time(min)/Headwayi_operated(min) +1.

3.5.9 Estimation of System Characteristics

For the analysis of the network, the following parameters are to be estimated.

Waiting_time : The average waiting time of a passenger is taken as the half of the headway of operation.

Passengers served by the route : Maximum passenger link flow for a period of operation considering the demand factor for that period is the total passengers served for that period by the route.

Total_waiting_time = Passengers served*0.5*Headway_operated.

Total_Km._operated=2*Route length*Trips_operated.

Km operated per bus : This parameter defines the utilization of the buses along the route.

Km_operated_per_bus = Kms_operated / No_of_buses.

3.6 Characteristics of the Graphics Package

3.6.1 Introduction

The whole routing submodel is developed as an interactive graphic package. The various capabilities of the package are discussed in the following sections. This helps the user/planner in taking decisions for choosing the routes by visualizing the network on the graphic screen. The approach is to combine heuristic and mathematical formulation with the user's experience in designing the transit network.

3.6.2 Description of the package

The following section elaborates the working of package.

1. Firstly, it will display the whole network for the proposed area of study. Fig 3.10 shows the display of the road network for the study area, Delhi. The package has the option either to route a particular MRTS station or to route for a range of MRTS stations starting from a particular station and ending to another station. It will ask the user to give the input for start of station and end of station, shown in fig 3.11.

2. Next comes the display of influence nodes for a MRTS station. This is shown in fig 3.12. The user has the option to select a particular node as a terminal or to give the package to select a terminal according to the criteria discussed in section 3.4. 4

3. It will generate the shortest path between the terminal and MRTS station as well as the no of alternatives based on the criteria discussed in section 3.4.5. Fig 3.13 displays the alternatives with their characteristic values. Again it will ask the user whether he wants

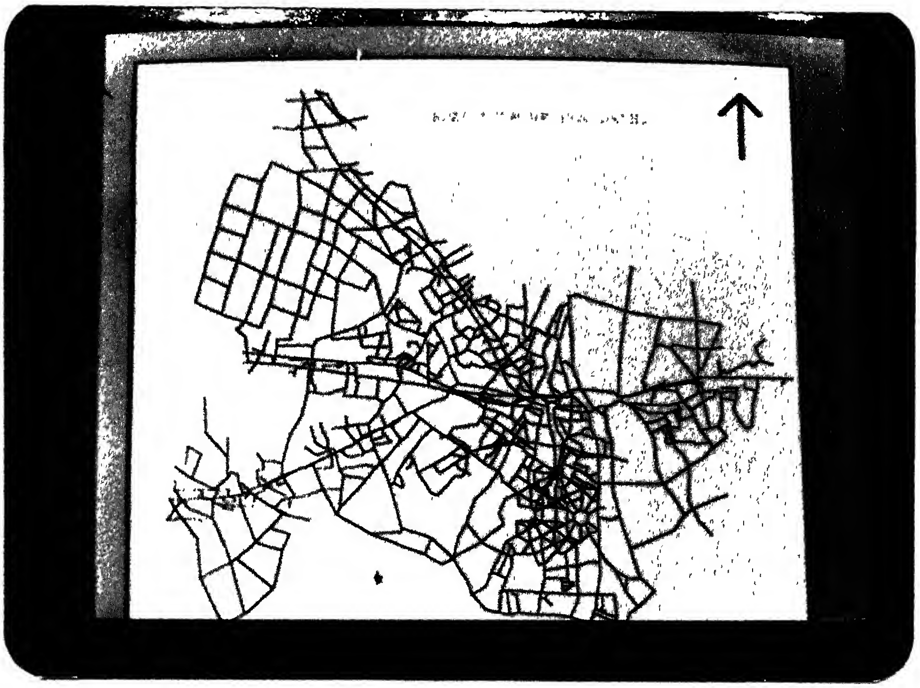


Figure 3.10: Display of Road Network for the Study Area(DELHI)

STARTING STATION : 6

ENDING STATION : 11

Figure 3.11: Graphic Screen for The Input of Stations

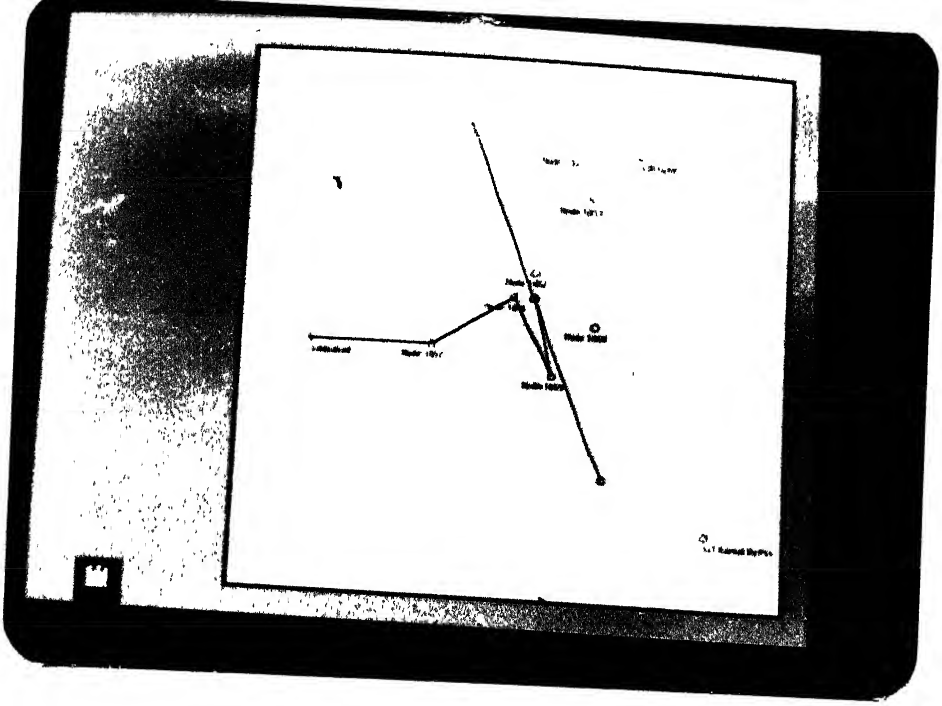


Figure 3.14: Graphic screen for one alternative route

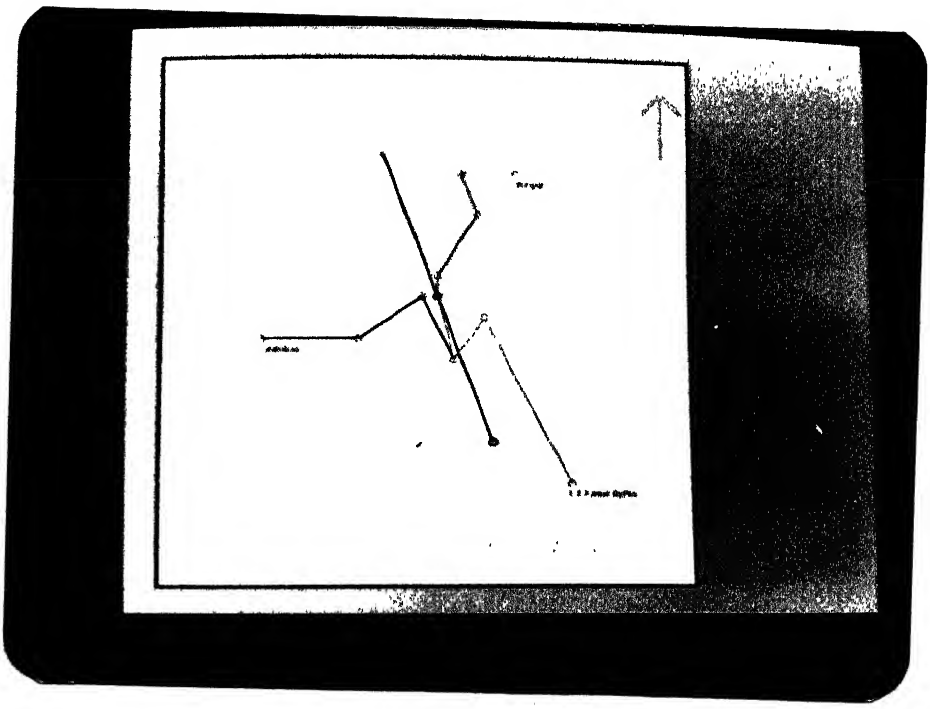


Figure 3.15: Display of selected routes for a MRTS station

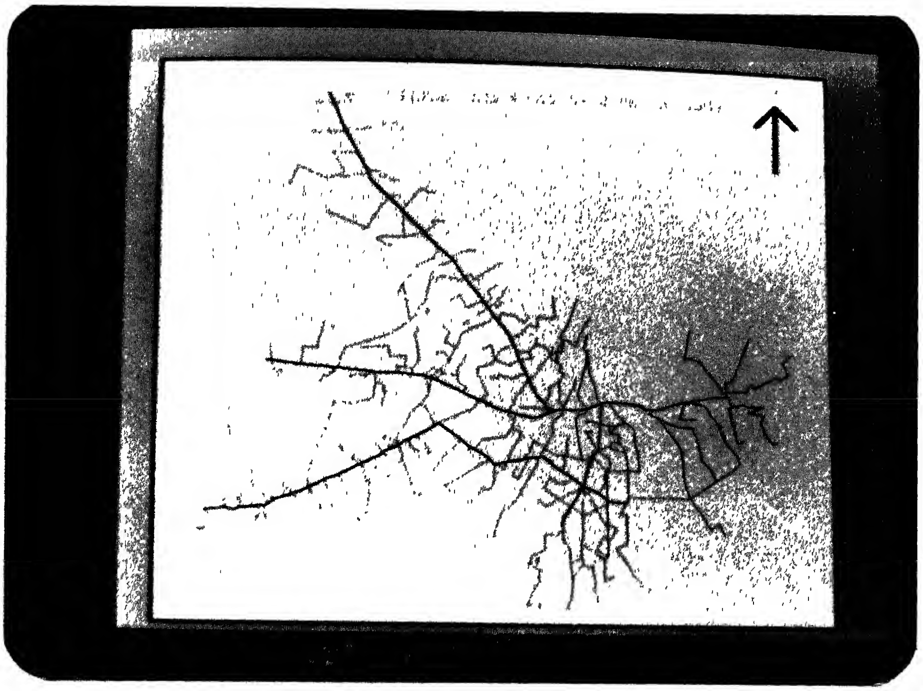


Figure 3.16: Display of feeder bus route network for MRTS

to include any particular important node. Depending on the user prompt it may/may not generate the alternative path by including this particular node. This path has been generated by adding two shortest paths, one from start node to this intermediate node and the other from this intermediate node to the end node. The user has the option to select any of these routes by displaying the routes one by one on the graphic screen to visualize the real world situation. One of the alternatives are shown in fig 3.14.The selection of routes depends on the label of satisfaction of the user.

4. When the selection of route is over, it will ask the user whether it will go for further generation of routes or not. Depending on the user prompt it will work. From the remaining untouched nodes in the influence area of that particular station, it will select the terminal according to the same criteria in section 3.6.2(2) and follow the same procedure discussed in section 3. 6.2(3). This procedure will go on until the user/planner is being satisfied and the maximum number of nodes in the influence area of that particular MRTS station are being touched. It will display the selected routes for that station. Fig 3.15 shows the selected routes for a MRTS station one by one by pressing enter from keyboard. After routing operation for a station is over, it will go for the next and follow same procedure as discussed in the previous sections. At the end it will display the finally selected feeder bus route network for the MRTS stations. Fig 3.16 displays the feeder bus route network.

5. At all the stages error handling procedures are included, until and unless the users are not giving correct input so that the program will not terminate itself. It will give all the error messages asking for correct input. Regarding selection of routes, if the user wrongly selects a route, he has the option to reject that route. At this stage, one cannot go back if he selects the route. Whenever a path is finally selected, the path and its characteristics, such as length and demand satisfied per Km., are written on output file and also the input file for the scheduling program. is generated.

6. The scheduling program is also written in interactive way. The scheduling program can be run either by giving the input for a particular level of service and a particular period of study(peak/off-peak) or it can calculate the different parameters for all level of service and two period of study, namely peak and midday period. It has the option to write in different files. The program incorporates the variation of maximum and minimum headway, halt time, lay over time etc.

Chapter 4

Case Study Analysis

4.1 Overview

The model as described in the previous chapter should be tested and validated for the real world data. Delhi administration has taken a project for the implementation of MRTS. The total length of this MRTS corridor is 74.5 Km and the no of MRTS stations are 67. The MRTS will likely to be operational fully by the the year 2003. The feeder bus services are to be planned accordingly. Road transport network of Delhi is taken as the source of data required for the case study analysis to validate the proposed model.

4.2 Estimation of the Passenger Demand for Each MRTS Station

The Delhi metropolitan area has been demarcated into 192 zones and the total production/attraction for the interzonal transfers during the design period is estimated as 138 lac passengers per day. The total no of nodes in the network for planning of feeder bus services is 1272. Out of these zones,178 zones are using MRTS. The zones which are not coming under the influence area of MRTS are deleted from the demand matrix.

4.3 Characteristics of The Generated Feeder Routes

For each station, optimal feeder routes are generated from the influence area of that station after evaluation of the shortest and alternative paths generated by the package. Two paths are presented graphically. Out of these one (Fig 4.1) is at the intermediate stage before

selection and the other is (Fig 4.2) finally selected one. For the 67 MRTS stations, a total of 146 routes are selected. In the table 4.1 to table 4.5, the details of the routes such as route length, demand satisfied per kilometer and the path starting from a MRTS station and ending to a terminal node. There is a wide variation of the route length with a minimum of 1.1 km. and maximum of 9.4 km. The mean length of the route is 3.06 km. The frequency distribution of the routes are shown in Fig 4.3. The MRTS station Tilak Bridge has the maximum number of 5 routes.

The various characteristics of the different routes e.g. length, operating speed,round trip time etc are given in the table 4.3. The round trip time for the route varying between 16 and 81 minutes with an average value of 32 minutes. The demand satisfied by the route is as high as 24504 passengers per day.

4.4 Scheduling Characteristics of The Feeder Routes

The algorithm, discussed in the previous chapter, schedules the buses for any time period under diff level of service condition. for the design year 2004, the design of optimal scheduling plans for the generated routes are carried out. The study is conducted for four level of service(LOS). LOS is defined in terms of bus loads. The characteristics of four LOS is shown in table 4.6 . The study period is also divided into two,namely peak and midday(off peak). The demand factor for these two periods are

Period	Period Demand (in percent of daily demand)
peak (8 - 11 am, 5 - 8 pm)	0.25
midday (off peak) (11 am - 5 pm)	0.31

The various parameters for the peak period condition under the LOS 1 is tabulated in table 4.7 to 4.11.

Table 4.1: Characteristics of route details

No	Distance (m)	Demand Satisfied (per Km)	Path
1	2630.00	23.06	101 1004 1005 1001 1002
2	1520.00	9.81	101 1004 1003
3	2860.00	25.20	102 1013 1014 1016 1017 1018 1019
4	2520.00	29.59	102 1013 1012 1011 1010 1009 1008
5	2450.00	8.66	103 1021 1023
6	5140.00	14.39	104 1024 1031 1030 1029 1028 1022 7052
7	1880.00	18.30	104 1024 1025 1026 1033 1034 1035 1036
8	4250.00	3.72	105 1047 7061 7062 7063
9	3120.00	9.62	105 1038 1044 1039 1040 1041 1042
10	4110.00	10.78	106 1046 1048 1057 1056 1055 7066 7065
11	2850.00	17.05	106 1045 1044 1039 1040 1041 1042
12	2760.00	9.77	107 1059 1058 1057 1056
13	1750.00	5.40	107 1052 1053 1049 1050
14	3470.00	14.18	108 1061 1064 1066 7064 7068 7070
15	3960.00	17.14	109 1067 3201 3204 3215
16	1420.00	4.99	109 1065 1062 1063
17	2180.00	10.91	110 3269 3269 1073 3488 3489 3490 3491 1072
18	1920.00	6.34	110 3269 3268 3267 3266 3265 3264
19	1240.00	3.81	110 1073 3488 3489 3402
20	2450.00	3.98	111 3405 3206 3203 3205
21	1680.00	15.39	111 3410 3407 3411 3497 3496 3495 3503
22	1570.00	7.75	111 3409 3412 3423 3214 3216
23	1480.00	12.78	111 3406 3404 3492 3493 3502
24	2960.00	14.14	112 3424 3417 3428 3430 3432 3434 3222 3230 3232
25	2130.00	5.81	112 3425 3413 3419 3426 3429 3420
26	4340.00	4.12	113 3437 3438 3439 3431 3433 3421 3422 3427 3606 3601
27	2040.00	5.05	113 3448 3443 3451 3455 3462 3447 3454
28	1910.00	11.65	113 3453 3457 3458 3449 3440
29	2570.00	4.74	114 3464 3466 3462 3463 3465 3468 3500
30	2510.00	8.74	114 3460 3458 3449 3450 3501 3620

Table 4.2: Continuation of Table 4.1

No	Distance (m)	Demand Satisfied (per Km)	Path
31	4930.00	6.03	115 3486 3471 3467 3628 3624 3618 3617 3609 3602
32	5110.00	1.05	115 3486 3471 3467 3628 3632 3624 3627 3618 3619 3621 3613 3608
33	3050.00	10.39	115 3486 4403 4402 4401 4407 4415 4418 4428 4432 4435 128
34	2450.00	5.29	115 3486 3470 3484 3483 3482 3481 3480 3479 3478 3477 3476 3475
35	2590.00	9.87	116 4412 4410 4408 4603 4602 3642 3639 3637 3633 3632
36	2020.00	23.32	117 2009 2004 2002 7023
37	1750.00	15.58	117 2009 2013 2014 2016
38	3380.00	28.55	118 2011 2006 2005 3005 3006 3002 7020 7058
39	2140.00	20.48	119 3032 3014 3017 3016 3027 3026 4006 4005
40	6480.00	16.43	120 3034 3012 3007 3003 3001 3215 7068
41	3150.00	7.42	121 3021 3030 3022 3023 4007 4017 4020
42	2880.00	8.62	121 3021 3030 3022 3023 4007 4010 4011 4014 4015 4022
43	1780.00	7.56	122 3023 3022 3030 3021 3020 3029 3019 4002
44	1500.00	16.56	122 3023 4007 4010 4011 4014 4015
45	4150.00	4.86	123 3256 3255 3244 3245 3237 3241 3004 3008
46	1730.00	2.44	123 3256 3255 3244 3245 3246 3242
47	5530.00	4.78	124 3258 3250 3253 3254 3243 3232 3227 3220 3211 3207 3208 3210
48	5280.00	11.01	124 3258 3257 3246 3242 3238 3225 3223 3218 3218 3217 3215 7068
49	1970.00	3.64	124 3258 3250 3253 3254 3270 3262 3263
50	3130.00	19.01	125 4254 3261 3270 3254 3253 3260 4207 4211 4213 4214
51	2620.00	3.10	125 4254 3261 3270 3254 3243 3234 3233 3239
52	2460.00	7.78	126 4209 4205 4202 3263 3251 3252 3240 3236
53	3630.00	6.04	127 4423 4416 4414 4409 3473 3500 3468 3465 3463
54	3350.00	7.77	127 4416 4414 4429 4217 4220 4219
55	2420.00	12.99	128 4435 4437 4438 4442 4446
56	2040.00	5.37	129 4433 4427 4426 4425
57	3300.00	12.36	130 4615 4619 4624 4623 4632 4638 4646 4647 4455 4463 157
58	2760.00	6.44	130 4615 4613 4611 4602 3642 3639 3637 3633 3632
59	1980.00	2.95	130 4615 4613 4607 4605 3643
60	3810.00	2.33	131 4609 4606 4601 3629 3625 3623 3615

Table 4.3: Continuation of Table 4.2

No	Distance (m)	Demand Satisfied (per Km)	Path
61	3290.00	7.43	131 4617 4621 4622 4620 4625 4650 4670
62	4310.00	3.54	132 4608 4630 4636 4856 4860 4873 4883 4892
63	3690.00	3.48	132 4612 4604 3640 3629 3625 3623 3615
64	9400.00	4.75	133 4831 4837 4842 4837 4842 4862 4875 4877 4896 5803 5805 5809 5808 5812
65	5810.00	4.41	133 4831 4837 4842 4852 4853 4857 4864 4869 4880 4886 4891 4895 4895
66	6060.00	8.65	134 4822 4819 4824 4838 4847 4855 4871 4888 4889 4894 4895
67	1620.00	6.18	134 4822 4835 4843 4844
68	5650.00	11.59	135 4809 4804 4805 4916 4898 4899 3822 3823 3821 3820 3819
69	4880.00	17.04	135 4809 4804 4803 3811 3810 3809 3808 3804
70	4450.00	9.95	135 4814 4815 4816 4816 4817 4820 4826 4821 4828 4908 4836 4909 4911 4912 4913 4914
71	3470.00	8.23	135 4809 4804 3816 3817 3814 3806
72	2850.00	8.22	135 4814 4815 4816 4817 4820 4826 4833 4839 4872 4866
73	4300.00	6.39	136 2067 2081 2084 7101
74	1800.00	7.55	136 2068 2069 2083
75	1700.00	8.35	136 2067 2078 2081 2080 2079
76	3780.00	10.42	137 2053 2054 2036 2037 2038 2030 2023
77	2350.00	8.78	137 2053 2054 2036 2035 2034 2029
78	4840.00	10.06	138 2055 2045 2046 2040 2039 2026 2025 2022 2018 2017
79	4420.00	3.98	138 2055 2045 2046 2040 2039 2038 2030 2021 2020
80	3120.00	9.74	139 2047 2059 2065 2072 2073 7104
81	2150.00	12.02	140 2056 2048 2047 2041 2040 2039 2038 2037
82	2510.00	10.23	140 2048 2043 2049 2033 2110 2095 2096 2094 2093 2092
83	1840.00	7.62	140 2048 2047 2109 2055 2045
84	1840.00	5.22	140 2048 2031 2028 2027 2026 2025
85	1620.00	10.20	140 2056 2073 2072 2076 2075
86	1470.00	8.43	140 2056 2073 2072 2071 2070
87	1260.00	3.28	140 2056 2073 2074
88	3090.00	16.47	141 2043 2049 2057 2058 2107 7106 7105
89	1620.00	7.11	141 2043 2033 2042 2032 2031 2028 2027
90	2760.00	7.70	142 2096 2097 2099 2095 2091 2089 2090 2087 2086 2085

Table 4.4: Continuation of Table 4.3

No	Distance (m)	Demand Satisfied (per Km)	Path
91	1400.00	14.07	142 2097 2099 2104 2102 2103 5007
92	5360.00	6.69	143 5003 4057 4033 4023 4018 4019 4020
93	1950.00	10.10	143 5004 5008 5010 5009 5012
94	2370.00	7.89	144 4064 5011 5010 5009
95	1910.00	5.16	144 4064 5003 5004 2106 2105
96	2680.00	16.07	145 4060 4061 5005 5016
97	3270.00	7.57	146 4054 5001 5002 5006 5013 5014
98	2840.00	5.46	146 4054 5001 4063 4251 4252
99	2370.00	13.33	146 4050 4047 4049 4046 4043 4040 4035 4034 4032 4026
100	2260.00	17.57	147 4051 4050 4047 4049 4046 4036 4027 4025
101	2010.00	5.97	147 4041 4028 4031
102	1260.00	6.55	147 4051 4059 4247
103	2300.00	20.71	148 4045 4041 4228 4227 4234 4226 4229 4232
104	1470.00	10.55	148 4045 4246 4245 4241
105	1380.00	14.34	148 4050 4047 4049 4046 4036
106	1100.00	9.47	148 4050 4053 4048
107	5200.00	15.55	149 4228 4030 4227 4222 4218 4216 4213 4211 4207 3259 3258 124
108	3680.00	9.52	149 4227 4234 4241 4245 4250 5207 5208 5209
109	1830.00	9.96	150 4223 4225 4233 4243 4244 4236
110	1250.00	11.54	150 4226 4229 4230 4235 4240 4242
111	4680.00	15.82	151 4219 4214 4213 4211 4207 3260 3253 3254 3243 3232
112	3220.00	5.66	151 4219 4220 4217 4429 4414 4409
113	4820.00	4.82	152 4231 4224 4220 4217 4429 4414 4409
114	2590.00	1.76	152 4231 4237 4248 5202 5203
115	2400.00	13.54	153 4238 4239 4451 4452 4449 4446 4442
116	2560.00	1.99	154 4475 4253 5204
117	5390.00	7.41	155 4469 4472 4477 4479 4474 4473 5402 5406 5405 5211 5210 5204
118	2380.00	11.31	155 4469 4456 4447 4445 4441 4437
119	2360.00	5.44	156 4465 4466 4485 4482 4478 4480
120	1710.00	10.30	156 4465 4454 4453 4448 4450 4455

Table 4.5: Continuation of Table 4.4

No	Distance (m)	Demand Satisfied (per Km)	Path
121	5040.00	1.53	157 4467 4671 4676 4463 4483 5403 5404 5409 5412 5417
122	2270.00	21.88	158 4918 4677 4672 4667 4663 4655 4649
123	1900.00	3.20	158 5603 5602 5601 4486 5408
124	7100.00	1.55	159 5721 5612 5613 5621 5640 5648 5657 5666 5669 5674 5675 5676 5690 5689 5691 5688 5699 5703 5707 5718 5720
125	6760.00	1.85	159 5721 5612 5620 5638 5653 5664 5671 5685 5696 5705 5709 5715 5716 6601 6619 6620 6614
126	2730.00	3.10	159 5721 5610 5609 5635 5634 5633 5414 5411
127	2420.00	3.87	160 5623 5615 5607 4678 4673 4668
128	1890.00	3.74	161 5626 5657 5656 5664 5651
129	5150.00	2.01	162 5631 5630 5629 5630 5629 5801 5802 5803 4895
130	4930.00	0.96	162 5631 5630 5629 5618 4679 4678 5703 5707 5718 5720
131	4620.00	2.21	162 5631 5659 5660 5677 5679 5695 5700 5700 5817 5818 6801
132	3390.00	2.42	162 5631 5630 5629 5618 4679 4678 4673 4668
133	3800.00	10.25	163 4689 4634 4637 4644 4645 4654 4661 4675 4679 4892
134	3230.00	2.91	163 4689 4634 4637 4635 4636 4856 4860 4873 4883
135	3490.00	9.35	164 4659 4658 4656 4657 4653 4654 4645 4644 4634 4689 4627
136	2140.00	7.73	164 4659 4665 4668 4670 4650
137	1770.00	5.85	164 4659 4669 4674 4678 4682
138	1530.00	5.32	164 4659 4658 4660 4661
139	1460.00	2.54	164 4659 4641 4642 4643
140	3000.00	2.87	165 4668 4673 4678 4679 4892
141	2960.00	5.90	165 4668 4670 4667 4664 4458 4455
142	4510.00	1.30	166 5647 5651 5664 5671 5685 5696 5698 5706 5704 5707 5718 5720
143	2170.00	2.77	166 5647 5646 5633 5632 5408 4486
144	6570.00	1.80	167 5668 5681 5682 5419 5423 5422 5425 5424 5426 5430 5432 6403 6406 6407 6408 6410
145	5360.00	0.80	167 5668 5681 5692 5697 5708 5705 5709 5712 5713 5717 6603 6606 6609 6612
146	4670.00	1.03	167 5668 5681 5692 5697 5708 5715 5716 6601 6619 6620

Level of Service	Maximum Bus Load	Average Bus Load
1	45	30
2	60	40
3	75	50
4	90	60

Table 4.6: Characteristics of different level of service

Scheduled time headways of operation for 146 routes range between 3 and 20 minutes with an average of 9 minutes. The number of bus trips are varying between 9 and 60. Result shows that the average trips for 146 routes are 29 for peak period of 3 hour duration. While during midday period the average trips are 43 with the variation between 18 and 120. The number of buses required for operation of the routes are ranging between 2 and 17 for highest level of service under peak period condition. This reduces with the deterioration of level of service. During midday period the number of buses required within the scheduled trip range are much less than that of during peak period for any level of service. The no of parking lots required at the road terminal and MRTS station to operate the scheduled trips of different routes vary between 1 and 4 for highest level of service during peak period. The fleet size required at LOS 1 to operate all 146 routes is 816. The total km operated by a route depends upon the number of scheduled trips and the route length. The vehicle operating distance has a wide variation among the 146 routes with the minimum value of 84 kilometers and maximum value of 777 kilometers and the average one is 174 kilometers during peak period at LOS 1. While for midday period at the same LOS this is much higher. The minimum, maximum and average values of vehicle operating distance during off peak period at LOS 1 are 168 km., 1356 km. and 257 km. The waiting time of a passenger in a route depends upon the headway of operation. For first level of service the variation of total waiting time for the passengers served for all routes is 60 hrs and 1503

Table 4.7: SCHEDULING PLAN at LEVEL OF SERVICE I (Peak Period-3 Hours: 8-11am, 5-8 pm) Design Year-2004

No	Length (km)	No of Trips	Head way (min)	No of Buses	No of Parking Lots	Waiting Time (hr)	Total Bus Km	Km per Bus	Max Link Flow	Average Link Flow
1	2.63	60	3	9	3	296	315	35	11867	2437
2	1.52	60	3	7	3	175	182	26	7022	2495
3	2.86	18	10	3	2	952	102	34	11432	520
4	2.52	60	3	10	3	466	302	30	18644	5401
5	2.45	60	3	8	3	132	294	36	5302	2705
6	5.14	60	3	13	3	387	616	47	15484	3314
7	1.88	45	4	7	3	191	169	24	5734	1220
8	4.25	36	5	7	3	164	306	43	3948	985
9	3.12	60	3	10	3	253	374	37	10121	2433
10	4.11	60	3	12	3	237	493	41	9505	1734
11	2.85	60	3	10	3	303	342	34	12146	2386
12	2.76	26	7	4	2	273	141	35	4694	680
13	1.75	20	9	3	2	132	70	23	1772	547
14	3.47	45	4	8	3	341	312	39	10250	1300
15	3.96	60	3	10	3	424	475	47	16965	3213
16	1.42	15	12	2	2	118	42	21	1182	433
17	2.18	16	11	3	2	270	71	23	2954	461
18	1.92	14	13	2	2	263	53	26	2435	406
19	1.24	22	8	3	2	157	55	18	2364	648
20	2.45	20	9	3	2	136	98	32	1826	574
21	1.68	22	8	4	2	352	75	18	5282	629
22	1.57	18	10	3	2	152	56	18	1826	512
23	1.48	20	9	3	2	221	59	19	2955	599
24	2.96	36	5	7	3	307	213	30	7369	996
25	2.13	9	20	2	2	363	38	19	2182	205
26	4.34	11	17	3	2	615	91	30	4346	300
27	2.04	13	14	2	2	204	52	26	1749	369
28	1.91	26	7	4	2	251	98	24	4311	677
29	2.57	13	14	3	2	314	66	22	2696	367
30	2.51	45	4	8	3	182	225	28	5484	1202

Table 4.8: Continuation of Table 4.7

No	Length (Km)	No of Trips	Head way (min)	No of Buses	No of Parking Lots	Waiting Time (hr)	Total Bus Km	Km per Bus	Max Link Flow	Average Link Flow
31	1.93	20	9	5	2	324	197	39	4321	543
32	5.11	15	12	4	2	356	153	38	3563	432
33	3.05	45	4	10	3	204	274	27	6149	1230
34	2.45	18	10	4	2	196	88	22	2354	529
35	2.59	20	9	4	2	421	103	25	5620	542
36	2.02	60	3	8	3	184	242	30	7385	3035
37	1.75	60	3	8	3	170	210	26	6818	1948
38	3.38	60	3	11	3	463	405	36	18529	2522
39	2.14	60	3	10	3	217	256	25	8685	2435
40	6.48	60	3	15	3	612	777	51	24504	2042
41	3.15	18	10	4	2	361	113	28	4344	538
42	2.88	36	5	7	3	284	207	29	6830	925
43	1.78	26	7	4	2	196	91	22	3362	737
44	1.50	60	3	8	3	155	180	22	6209	1987
45	4.15	9	20	2	2	463	74	37	2780	234
46	1.73	10	18	2	2	217	34	17	1452	294
47	5.53	20	9	6	2	393	221	36	5246	569
48	5.28	45	4	12	3	484	475	39	14540	1322
49	1.97	45	4	7	3	133	177	25	4019	1224
50	3.13	60	3	12	3	332	375	31	13282	1613
51	2.62	15	12	3	2	302	78	26	3027	439
52	2.46	30	6	5	2	179	147	29	3588	817
53	3.63	22	8	5	2	273	163	32	4108	622
54	3.35	45	4	9	3	239	301	33	7195	1181
55	2.42	36	5	7	3	261	174	24	6276	908
56	2.04	20	9	4	2	154	81	20	2056	544
57	3.30	30	6	7	2	470	198	28	9416	799
58	2.76	12	15	3	2	477	66	22	3819	360
59	1.98	10	18	2	2	124	39	19	833	286
60	3.81	9	20	3	2	324	68	22	1947	179

Table 4.9: Continuation of Table 4.8

No	Length (Km)	No of Trips	Head way (min)	No of Buses	No of Parking Lots	Waiting Time (hr)	Total Bus Km	Km per Bus	Max Link Flow	Average Link Flow
61	3.29	26	7	6	2	323	169	28	5550	759
62	4.31	36	5	9	3	135	310	34	3244	926
63	3.69	22	8	6	2	165	166	27	2476	604
64	9.40	11	16	6	2	1292	211	35	9691	330
65	5.81	15	12	5	2	807	174	34	8080	445
66	6.06	45	4	15	3	381	545	36	11434	1264
67	1.62	12	15	2	2	208	38	19	1668	340
68	5.65	60	3	17	3	305	678	39	12239	2383
69	4.88	26	7	6	2	1212	250	41	20787	682
70	4.45	9	20	3	2	1503	80	26	9020	264
71	3.47	45	4	9	3	237	312	34	7136	1090
72	2.85	9	20	2	2	598	51	25	3588	164
73	4.30	30	6	6	2	254	258	43	5092	793
74	1.80	22	8	3	2	147	81	27	2215	615
75	1.70	60	3	8	3	103	204	25	4139	1875
76	3.78	14	13	3	2	424	104	34	3920	394
77	2.35	30	6	5	2	258	141	28	5161	835
78	4.84	15	12	4	2	921	145	36	9218	438
79	4.42	9	20	2	2	813	79	39	4880	254
80	3.12	11	17	2	2	569	66	33	4020	309
81	2.15	9	20	2	2	320	38	19	1920	268
82	2.51	30	6	6	2	321	150	25	6420	895
83	1.84	36	5	5	3	146	132	26	3506	914
84	1.84	22	8	3	2	160	82	27	2400	652
85	1.62	30	6	4	2	146	97	24	2926	867
86	1.47	36	5	5	3	121	105	21	2926	955
87	1.26	18	10	2	2	114	45	22	1377	525
88	3.09	11	16	3	2	1356	69	23	10175	329
89	1.62	9	20	2	2	320	29	14	1920	261
90	2.76	16	11	4	2	324	90	22	3542	488

Table 4.10: Continuation of Table 4.9

No	Length (Km)	No of Trips	Head way (min)	No of Buses	No of Parking Lots	Waiting Time (hrs)	Total Bus Km	Km per Bus	Max Link Flow	Average Link Flow
91	1.40	30	6	4	2	61	84	21	1231	809
92	5.36	45	4	11	3	269	482	43	8078	1206
93	1.95	60	3	9	3	123	234	26	4924	1894
94	2.37	60	3	9	3	92	284	31	3693	2213
95	1.91	60	3	9	3	114	229	25	4578	2085
96	2.68	60	3	10	3	143	321	32	5756	2320
97	3.27	45	4	8	3	154	294	36	4642	1136
98	2.84	45	4	8	3	146	255	31	4393	1238
99	2.37	14	13	3	2	532	65	21	4912	415
100	2.26	30	6	5	2	395	135	27	7915	841
101	2.01	45	4	6	3	133	180	30	4003	1095
102	1.26	22	8	3	2	68	56	18	1032	630
103	2.30	45	4	8	3	229	207	25	6876	1136
104	1.47	60	3	8	3	96	176	22	3878	1424
105	1.38	36	5	5	3	247	99	19	5950	1035
106	1.10	18	10	2	2	163	29	14	1965	497
107	5.20	60	3	16	3	282	624	39	11290	1737
108	3.68	16	11	4	2	636	120	30	6944	472
109	1.83	36	5	6	3	97	131	21	2349	1001
110	1.25	10	18	2	2	176	19	9	1174	284
111	4.68	60	3	15	3	384	561	37	15397	3454
112	3.22	45	4	8	3	95	289	36	2858	1110
113	4.82	36	5	9	3	222	347	38	5337	997
114	2.59	12	15	2	2	142	62	31	1137	351
115	2.40	14	13	3	2	339	66	22	3138	405
116	2.56	11	16	2	2	169	57	28	1271	333
117	5.39	18	10	5	2	605	194	38	7270	513
118	2.38	45	4	7	3	224	214	30	6732	1273
119	2.36	18	10	3	2	81	84	28	978	497
120	1.71	45	4	7	3	146	153	21	4402	1210

Table 4.11: Continuation of Table 4.10

No	Length (Km)	No of Trips	Head way (min)	No of Buses	No of Parking Lots	Waiting Time (hr)	Total Bus Km	Km per Bus	Max Link Flow	Average Link Flow
121	5.04	9	20	3	2	60	90	30	363	48
122	2.27	60	3	11	3	310	272	24	12415	3282
123	1.90	16	11	3	2	139	62	20	1520	456
124	7.10	9	20	4	2	430	127	31	2582	29
125	6.76	9	20	4	2	510	121	30	3065	136
126	2.73	15	12	3	2	200	81	27	2003	440
127	2.42	9	20	2	2	310	43	21	1860	269
128	1.89	20	9	3	2	104	75	25	1396	569
129	5.15	9	20	3	2	88	92	30	532	57
130	4.93	9	20	2	2	165	88	44	995	101
131	4.62	13	14	3	2	324	118	39	2779	361
132	3.39	9	19	2	2	294	64	32	1860	274
133	3.80	45	4	11	3	288	342	31	8652	1093
134	3.23	14	13	3	2	281	89	29	2602	387
135	3.49	36	5	9	3	268	251	27	6447	1053
136	2.14	9	20	2	2	500	38	19	3000	196
137	1.77	30	6	5	2	129	106	21	2589	892
138	1.53	30	6	4	2	115	91	22	2317	863
139	1.46	22	8	3	2	61	65	21	927	654
140	3.00	9	20	2	2	271	54	27	1630	250
141	2.96	26	7	5	2	254	152	30	4363	752
142	4.51	9	20	3	2	196	81	27	1178	84
143	2.17	9	19	2	2	215	41	20	1359	282
144	6.57	9	20	3	2	432	118	39	2592	138
145	5.36	9	20	3	2	148	96	32	891	50
146	4.67	9	20	2	2	170	84	42	1020	66

hrs with the average value of 301 hrs during peak period. While during midday period the waiting time for the routes are much higher and varying between 75 hrs and 2577 hrs with the average value of 525 hrs. The vehicle utilization parameter, kilometer operated per bus, are estimated for each route for the period of operation. Results report that for the peak period of 3 hours duration at highest level of service, on an average a bus is operated for 28 km with the variation between 9 km and 51 km. There is also much difference between midday and peak period. During midday period the bus is plying 32 km with the maximum and minimum value of 16 and 81 km.

4.5 Scheduling Characteristics For The System

The operating characteristics for the scheduling plan of the entire feeder route system are given in table 4.12 and table 4.13 for four level of services and two period of study. For LOS 1 during peak period condition the total fleet size is reported as 816. But it is only 535 for LOS 4 due to the poor operating condition. The fleet size during off peak period is (618) less than the fleet size during peak period condition. So the design fleet size would be

Table 4.12: System Operating Characteristics Peak Period

LOS	Fleet size	Total buskm operated	Km per bus	Total pass wait time (hr)	Avg. waiting time (min)	Avg. bus load	Avg. load factor
1	816	25543	29	44407	3.5	32	0.53
2	692	21345	28	54518	4.2	38	0.63
3	601	18372	28	63531	4.9	45	0.75
4	535	16084	27	70829	5.5	52	0.87

according to the peak period condition. During peak period the buses will be plying on an average about 29 km. While for midday period this value is much higher.Due to the poor level of service though the fleet size is reducing steeply, km operated per bus is reducing very slightly. System waiting time is increased at LOS 4 compared to LOS 1 due to lesser number of buses operated. The average waiting time for a passenger during peak

period is 3.5 minutes at highest level of service, while this is 5.5 minutes at poorest level of service. During midday period a passenger waits for 4.8 minutes for a bus at LOS 1, while he has to wait for 7.1 minutes for a service at Los 4. The average load factor during peak period is 0.53 while this is 0.45 during midday period at LOS 1. Due to poor operating condition these values are 0.87 and 0.75 respectively during peak and off peak period at LOS 4.

The relationship for different level of service between the

a. Fleet size - Waiting time (Fig 4.4 and Fig 4.5)
b. Fleet size - Total km operated (Fig 4.6 and Fig 4.7)
c. Fleet size - Km operated per bus (Fig 4.8 and Fig 4.9)
d. Fleet size Average load factor (Fig 4.10 and Fig 4.11)

are presented in the following pages.

From the figure 4.4 and figure 4.5, it is clear that with the increase of fleet size, total passenger waiting time reduces both for peak and midday period due to the deterioration of operating condition. It corresponds to the real world situation. This is very much helpful in deciding the fleet size for the system for a fixed waiting time and it also shows the level of service condition for a fleet size.

Figure 4.6 and figure 4.7 says that there is a linear relationship between the fleet size and the total kilometers operated. As the fleet size increases, total kilometers processed

Table 4.13: System Operating Characteristics Off Peak Period

LOS	Fleet size	Total buskm operated	Km per bus	Total pass wait time (hr)	Avg. waiting time (min)	Avg. bus load	Avg. load factor
1	618	37663	55	76739	4.8	27	0.45
2	517	30847	54	91519	5.7	33	0.55
3	450	25836	53	103618	6.5	40	0.67
4	409	22913	52	113197	7.1	45	0.75

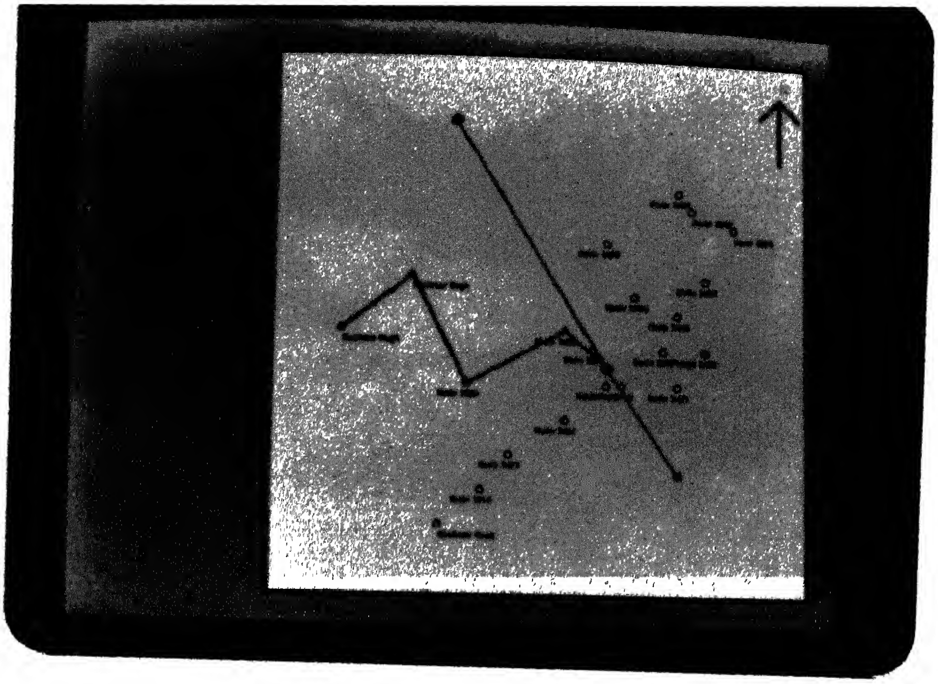


Figure 4.1: One alternative route before selection for a station

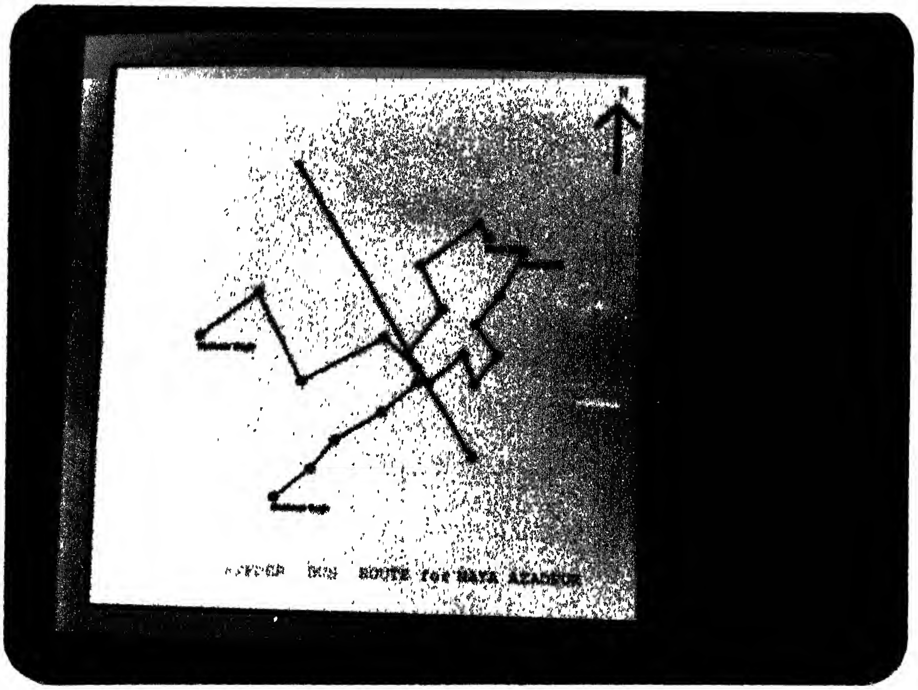


Figure 4.2: Selected routes for a MRTS station

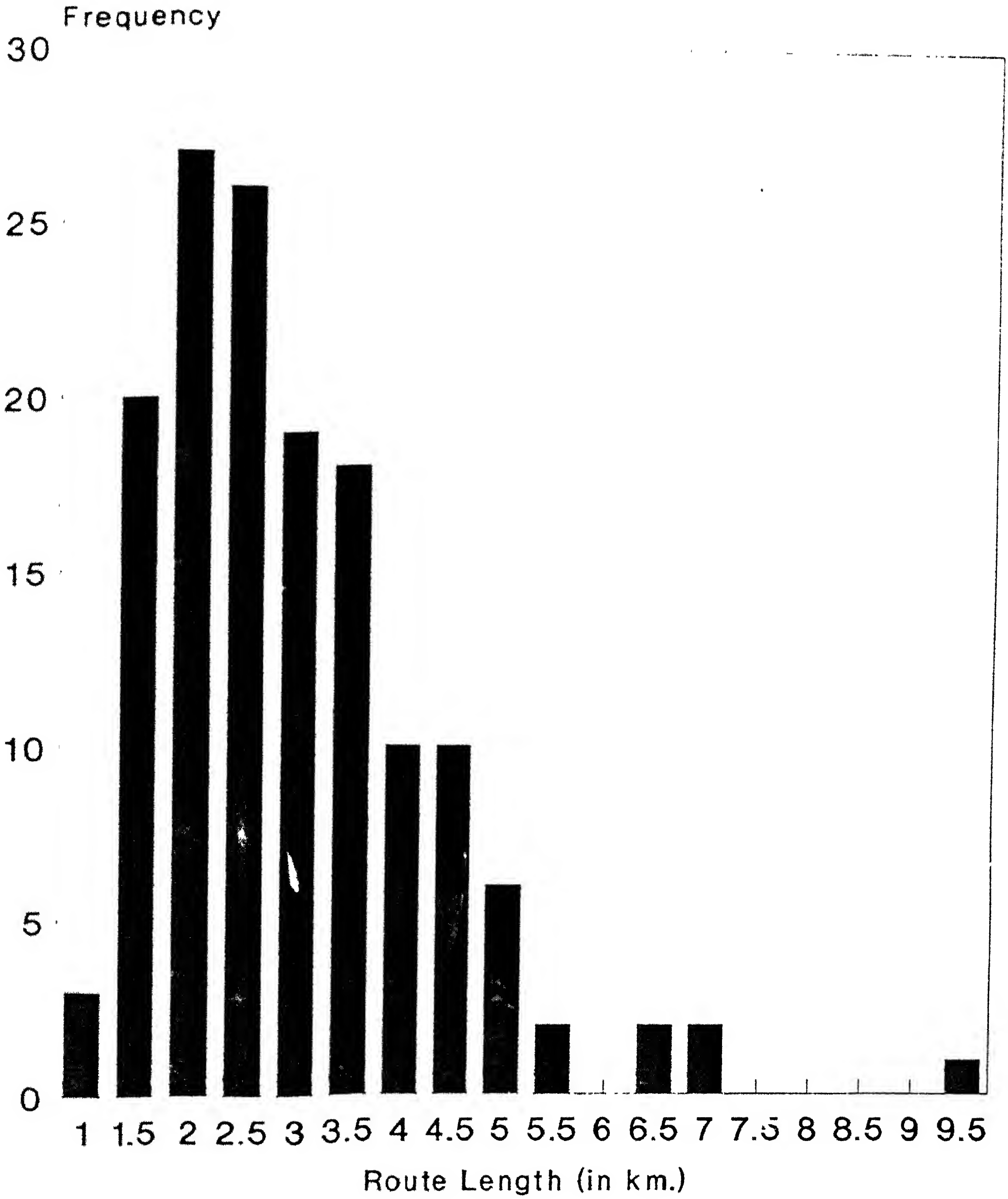


Figure 4.3: Frequency distribution of routes

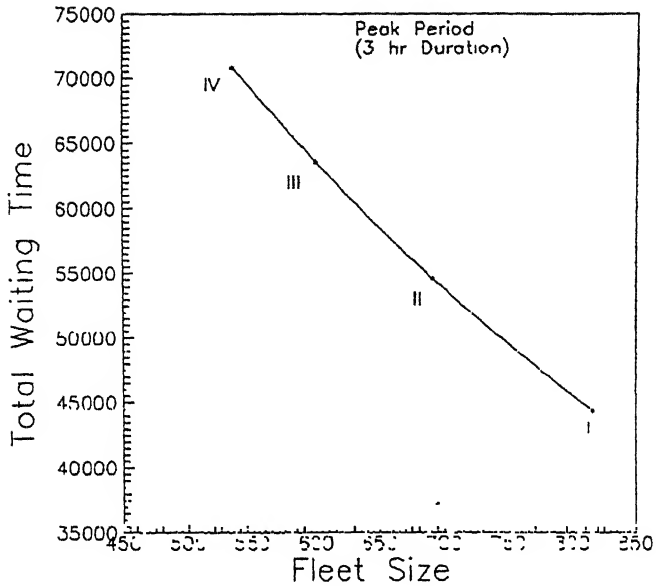


Figure 4.4: Relationship between fleet size and waiting time (peak period)

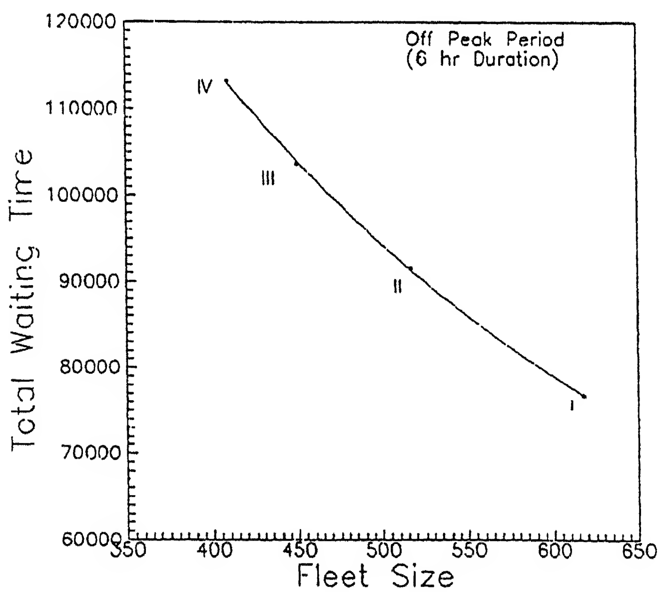


Figure 4.5: Relationship between fleet size and waiting time (off peak period)

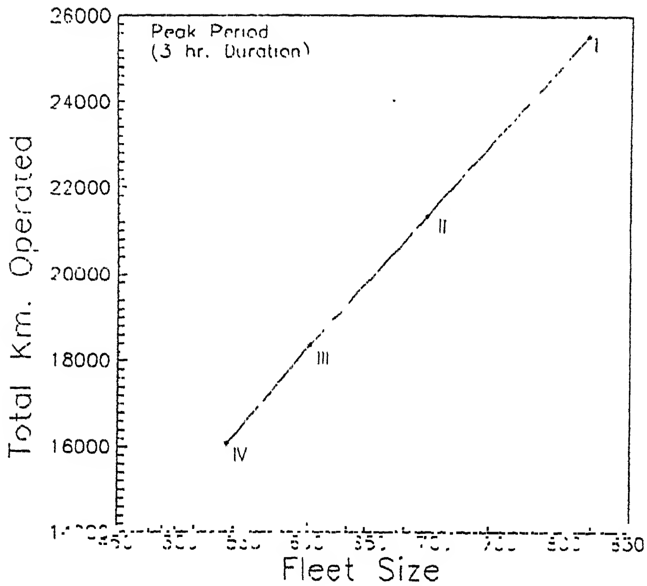


Figure 4.6: Relationship between fleet size and total km. operated (peak period)

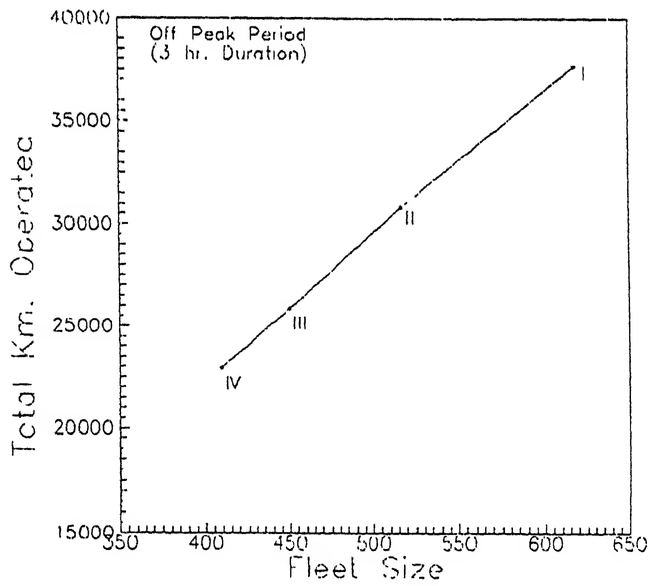


Figure 4.7: Relationship between fleet size and total km. operated (off peak period)

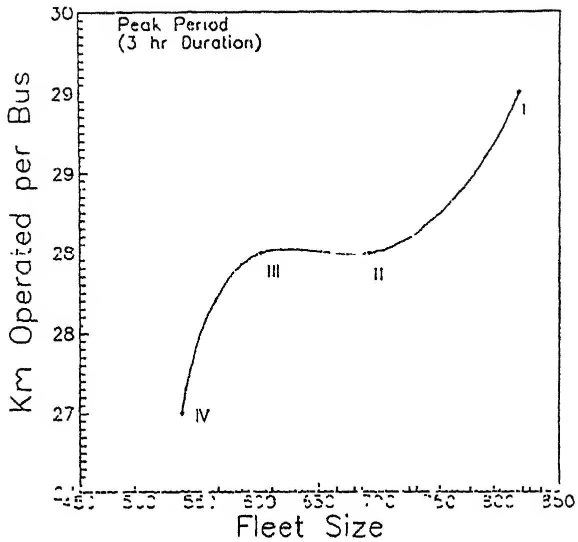


Figure 4.8: Relationship between fleet size and km. operated per bus (peak period)

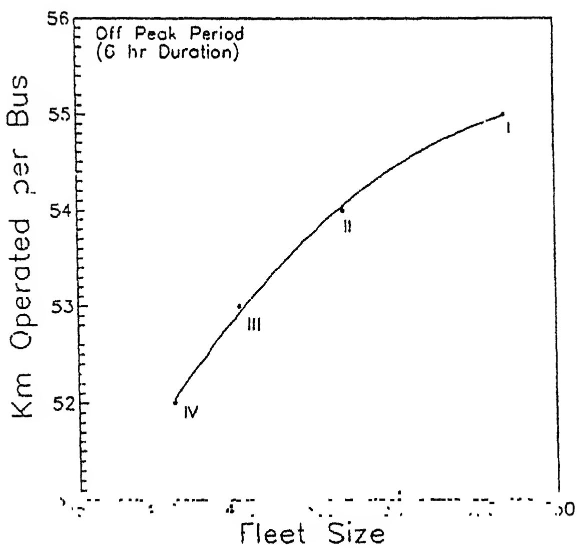


Figure 4.9: Relationship between fleet size and km. operated per bus (off peak period)

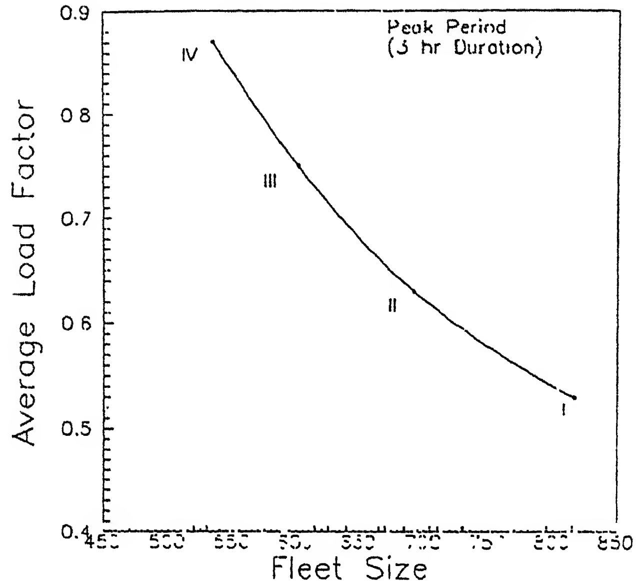


Figure 4.10: Relationship between fleet size and average load factor (peak period)

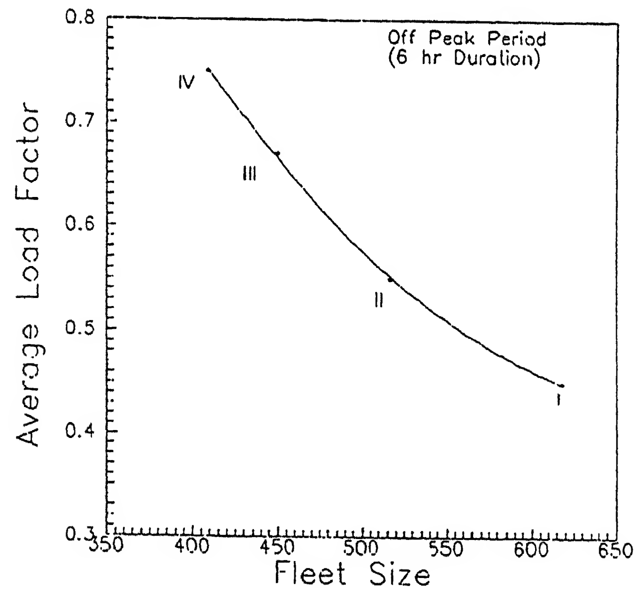


Figure 4.11: Relationship between fleet size and average load factor (off peak period)

also increases. Total kilometers depend on trips operated and route length. There is a direct relationship between the no of trips operated and the no of buses.

From fig. 4.8 and fig. 4.9 it is found that there is a marginal decrease of kilometers operated per bus with the decrease of fleet size. This parameter is very much important in terms of vehicle utilization.

Fig. 4.10 and fig. 4.11 depicts that with the increase of fleet size there is a parabolic decrease of average load factor. This parameter is also important in designing the fleet size for a network.

From the above discussion it is clear that the model developed with the interactive graphic system fits well to the study areas. Hence the package can be implemented successfully for any large metropolitan city for designing the feeder routes for the mass rapid transit system.

Chapter 5

Conclusions

5.1 Introduction

The past research in the area of modeling, methodologies and solution procedure for routing and scheduling problems has been reviewed and identified some of the deficiencies in the existing literature. There is also no such significant study in the area of mass rapid transit planning. The unique characteristic of the planning of feeder bus transit system is that the boarding and alighting of passengers occur unidirectionally. An attempt has been made in this study to plan the feeder bus routes with the interactive graphics system. and to schedule the buses optimally in the transit network. Detailed study methodology based on heuristic algorithm has been developed for this purpose. Graphics package has been very much helpful in evaluating and selecting the alternatives.

5.2 Case Study Analysis

5.2.1 General

The national capital Delhi has been considered for this study to validate the model. The Delhi metropolitan area has been demarcated into 192 zones. Out of these zones, 178 zones are coming under the influence area of the MRTS/road network. The total no of nodes in these influence zones 1272 with 1783 links passing through them. The nodes are coded by their number and the coordinates. The links are described by the nodes at the two ends. The total production/attraction for the interzonal transfers during the design period 2004 is 138 lac passengers per day. The bus journey speeds are varying among the MRTS stations and are within the range between 15 to 25 kmph.

5.2.2 Routing With The Help of Package

Feeder routes are generated separately for each of the MRTS station. From the influence area, a terminal is selected. With the help of package the alternatives are generated and tested for feasibility. The feasible alternative paths are evaluated to select the optimal path. The criteria of selection is based on the parameter demand satisfied per km. Generally the path with higher demand satisfied per km is being selected.

For the total 67 MRTS station, a total of 146 routes are selected. The length of the route is widely varied with a shortest route length of 1.1 km. and longest value of 9.4 km. The MRTS station Tilak Bridge has the maximum number of routes of 5. The round trip time depends on the the speed of the vehicle on the route, halt time at the stoppages and lay over time at the terminals.The round trip time for the routes are ranging between 16 and 81 minutes.

The graphic capabilities of the package are very useful in designing the route network. It helps the user to generate the feeder routes. If any routes are generated but it is not up to the user's expectation, it can be discarded altogether. The interactive nature and efficiency of program makes the package very convenient in designing the network. The graphic display of routes facilitate the user with choice to divert from any fixed criterion and include practically useful decisions.

5.2.3 Characteristics of The Scheduling Plans

As the aim is to schedule the buses in different routes, the design of experiment for the scheduling plan for the design year is as given below.

i) Scheduling time period : Both peak (8 - 11 am,5 - 8 pm) and off peak
(midday) period (11 am - 5 pm). The demand factor for the respective periods
in terms of percentage of daily demand are 0.25 and 0.31.

ii) Level of service (LOS) : LOS is defined in terms of maximum and average bus loads on the route. Four level of service are considered for the study purpose.

Results show that for the 146 selected routes, during peak period the total fleet size is 816 at LOS 1 and it is 535 at LOS 4 (poorest operating condition). During off peak period these values are much less. It is 618 and 409 at highest level of service and poorest level

of service respectively. Hence the fleet size would be determined based on peak period condition.

Daily passenger demand satisfied by the routes during peak period is 771820 while 957057 passengers are using the MRTS system daily during off peak period. The round trip time for the routes are varying between 16 and 81 minutes with an average of 32 minutes during peak period at LOS 1. The no of bus trips are ranging between 9 and 60 in each direction for the peak period of 3 hour duration. The scheduled time headways of operation are varying between 3 and 20 minutes with an average of 9 minutes. The bus kilometers operated by a route depends upon the length of the route and the number of scheduled trips to be operated. The highest and lowest value of total bus km operated is 84 and 777 with an average value of 174. To judge the vehicle utilization parameter, kilometer operated per bus is estimated for the period of operation. From the result it is seen that during peak period of 3 hour duration on an average each bus is plying for 28 kilometer.

The system waiting time at LOS 1 is 44407 hours. A passenger will wait about 3.5 minutes for a bus along a route. But at LOS 4, he has to wait for 5.5 minutes for a service. The km operated per bus for the system is about 29. The average load factor for the system is about 0.53 at highest level of service. At poorest level of service (LOS 4) this value is about 0.87.

The total km operated increases linearly with the increase of fleet size. There is a parabolic relationship between the system waiting time and fleet size. This curve is very much helpful in designing the fleet size for a certain restricted waiting time. This reflects the real world situation. There is a gradual decrease of load factor with the increase of fleet size.

5.3 Scope for Future Work

1. The heuristic algorithm for generating bus transit routes may not cover all alternatives. Further refinement of the suggested model may take care of the explicit enumeration of all alternatives.

2. The impact of other modes such as two wheelers, passenger car,tempo etc is not con-

sidered. It will change the demand pattern of the transport network.

3. The model is fully deterministic. The vehicle capacity, lay over time and halt time are being kept constant. Waiting time is considered as half of the headway of operation. The model can be worked with the probabilistic distribution of waiting time. Lay over time can be taken as a function of route length. One can work with the changing traffic volume through out the day.

4. Here it is considered that whenever a zone uses MRTS system, all the nodes within the zone will also use the MRTS system. This may not be true. If the farther zones which are of larger size are using MRTS system, the nodes in these zones which are closer to the MRTS system will come under the influence of the MRTS station, whereas the nodes which are far away from stations may not use MRTS system. This problem can be tackled by scanning node by node when the zone centroid is above some critical distance from MRTS line.

5. The routing package itself is not designing anything on its own. Everything depends on the user/planner. So the designing of the network will change from user to user. This program may be transformed to an expert system where the termination criteria for routing a station will have to be given by the user. So the program needs slight modification.

6. Existing bus transit network is considered for the study purpose. As the feeder routes are generated, the present route network should be modified. Some routes may be withdrawn and some new routes may be generated. For this purpose there is a need to study for restructuring the bus route network.

7. The feed back of scheduling program to the routing model may improve the routing package. For this program needs a very little change to modify it.

8. The criteria of level of service is considered based on the bus loads (percent bus full). The study can be conducted for a level of service based on passenger waiting time. There is a difference between the perceived waiting time and estimated waiting time. The level of service based on passenger waiting time can be considered so that the average waiting time should not be greater than some critical value or the probability of waiting time should not be greater than some critical value.

REFERENCES

(1) Axhausen, K.W. and Smith, R.L. " Evaluation of Heuristic Network Optimization Algorithms " , *Transportation Research Record* 1976.

(2) Bodin, L. and Golden, B. " Classification of Vehicle Routing and Scheduling", *Networks* V 11 pp 179-214, 1981.

(3) Bowman, L.A. and Turnquis, M.A. " Service Frequency, Schedule and Passenger Waiting Time at Transit Stops ", *Transportation Research* V 18A(3) pp 231-244, 1984.

(4) Budhesuden, Ranjithan, S and Singh, K.N. " The Design of Bus Route System - An Interactive Location Approach ", *Transportation* 14, pp 253-270 . 1987

(5) Carraress, P. and Gallio. G " Relaxation Approaches to Large Scale Bus Scheduling Problem", *Transportation Research* V 16B(5) pp 383-397, 1982.

(6) Chou, et.al. "The Planning of Urban Bus Routes and Frequencies : A Survey ", *Transportation* 12, pp 147-172 (1984)

(7) Cunningham, E.P. " A Dynamic Model for Vehicle Routing in a Two Way PRT System ", *Transportation Research*, pp 139-149 (1975)

(8) Dhingra, S.L. " Simulation of Routing and Scheduling of City Bus Transit Network " Ph.D. Thesis I.I.T.Kanpur, India (1980).

(9) Doi and Allen " A Timeseries Analysis of Monthly Ridership for An Urban Rail Rapid Transit Line ", *Transportation* V-13 pp 257-269 (1986).

(10) Dror, M., Gilbert, L and Trudeau, P " Vehicle Routing With Stochastic Demands Properties and Solution Framework ', *Transportation Science* V 23(3) 1989.

(11) Fisher, M.L. and Jaikumar, R. " A Generalized Assignment Heuristic for Vehicle Routing", *Networks* V 11 pp 109-124, 1981.

(12) Foster, B.A. and Ryan, D.M. " An Integer Programming Approach to The Vehicle Scheduling Problem", *Operation Research Quarterly* V 27 pp 367-384, 1976.

(13) Friedman, M. " A Mathematical Programming Model for Optimal Scheduling of Buses Departures Under deterministic Conditions ", *Transportation Research* pp 83-90 (1976).

(14) Furth, G.P. " Zonal Route Design for Transit Corridors ", V 20(1) pp 1-12 , 1986.

(15) Gulliot, E. " Bus Transit Interface With Light Rail Transit in Western Canada ", *Transportation Research* V 18A(3) pp 231-241, 1984.

(16) Hall, R.W. " Passenger Delay in a Rapid Transit Station ", *Transportation Science* V 21(4) pp 279-292, 1987.

(17) Haris, N.K. " Scheduling of extraboard operators in transit system ", *Transportation Science* V 24(2) pp 87-104, 1990.

(18) Hutchinson, B.G. " Principles of Urban Transportation Planning Systems" , McGraw Hill. (1974).

(19) Kikuchi, S. and Asce, M " Scheduling of Demand Responsive Transit Vehicles " *Journal of ASCE (Transportation Engineering)* V 110(6) pp 511-520,1984.

(20) Kikuchi, S. and Vuchic, V.R. " Transit Vehicle Stopping Regimes and Spacings " *Transportation Science* V 16(3) pp 311-331, 1982.

(21) Kyte, M. et al. " A Time Series Analysis of Public Transit Ridership in Portland and Oregon ", *Transportation Research* V 22A(5) pp 345-359.

(22) Marwah, B.R. "Planning of Feeder Bus Services for Delhi MRTS Phase-I" Project Report Submitted to RITES (1994).

(23) Marwah, B.R. and Patnaik, S.B. " Optimal Design of Bus Routes and Frequencies for Ahmedabad ", *Transportation Research Record*, 994 (1984).

(24) Marwah, B.R. and Sarna, A.C. " Optimum Routing and Scheduling of Vehicles for Mass Transportation in Kanpur Metropolis ", Project Report, Department of Science and Technology, Govt. of India, New Delhi. (1980).

(25) Morlok, E.K. " Introduction to Transportation Engineering and Planning ", McGraw Hill, Ch-8, (1978).

(26) Nuttle,H.L.W. " A Comprision of Heuristics for A School Bus Scheduling Problem", *Transportation Research* V 21B (4) pp 311-316 (1987).

(27) Orloff and Clifford " Route Constrained Fleet scheduling ", *Transportation Science(ORSA)* pp 149-168 (1976).

(28) Roe, T. and Shane, M. " Programming Approach to Urban Transit Planning", *Jour-*

nal of ASCE (Transportation Engineering) V 99(TE3) pp 571-584, 1973(Aug).

(29) Rubin, F. " Routing Algorithms for Urban Rapid Transit ", *Transportation Research* V-9 pp 215-223, (1975).

(30) Salzborn, F.J.M " Scheduling Bus System with ntERchanges ", *Transportation Science* V 14(3) pp 211-231, 1980.

(31) Schabas, M " A Comparison of Canberra and Springfield And Quantitative Analysis of Rapid Transit Alignment Alternatives ", *Transportation Quaterly* V-42 pp 403-416 (1988).

(32) Sikka, R.P. " Growing Crisis of Managing the Trunk Route System in india", *Indian Road Congress Journal* V 53-2 p 333, 1992(sep).

(33) Srinivasan, N.S. et al. " Optimization of Bus Transport in Aurangabad Region ", *Indian Road Congress Journal* V 44-4 p 917, 1984.

(34) Tsamboulas. D,Golias. J et al." Model Development for Metro Station Access Mode Choice ", *Transportation* V-19 pp 231-244 (1992).

(35) Tsao, S. et al. " Optimization of Zonal Transit Service", *Journal of ASCE(Transportation Engineering)* V 109(2) pp 257-272, 1983.

(36) Victor, D.J. and Santkumar, S.M. " Simulation Study of Bus Transit ", *Journal of ASCE (Transportation Engineering)* V 112(2), pp 119-211 (1986).

(37) Warren, W.D. " Impacts of Landuse on Mass Transit Development ", *Transportation Quarterly* V-42(2) pp 223-242 (1988,April).

(38) Wirasinghe, S.C. et al. " Rail Line Length in an Urban Transportation Corridor ", *Transportation Science* V 20(4) pp 237-245, 1986.